ANALYSIS OF CLIMATE CHANGE IMPACTS ON PLANT BIODIVERSITY AND LIVELIHOODS AMONG MAASAI WOMEN IN NAROK COUNTY, KENYA

BY

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DECLARATION

Declaration by Candidate

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I dedicate this work to my lovely wife Sheryl and my children: Caleb, Melvin and Precious.

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ABSTRACT

Climate change poses critical threats to plant biodiversity and pastoral livelihoods in sub-Saharan Africa, yet knowledge gaps persist regarding gender-differentiated impacts of climate-biodiversity interactions on women's livelihood vulnerability. This study assessed climate change impacts on plant species diversity and implications for Maasai women's livelihoods in Narok County, Kenya. A mixed-methods convergent design was employed, integrating quantitative climate data analysis (1990-2020), systematic botanical surveys, structured questionnaires (n=100 Maasai women), and qualitative assessments through focus group discussions (n=24 groups) and key informant interviews (n=15 traditional experts). Climate data from Kenya Meteorological Department and NASA POWER database were analyzed using Mann-Kendall trend tests and Sen's slope estimators. Ethnobotanical surveys utilized systematic transect-quadrat sampling across eight locations. Vulnerability assessment employed Hahn's Livelihood Vulnerability Index framework. Results revealed statistically significant warming of 0.35°C per decade (Mann-Kendall $\tau=0.312$, $p<0.01$) with extreme temperature events reaching 2.35°C above baseline. Precipitation showed high inter-annual variability (coefficient of variation=31.2%) with significant seasonal shifts including September increases ($\tau=0.338$, $p=0.009$) and February decreases approaching significance ($\tau=-0.251$, $p=0.054$). Botanical surveys documented 89 plant species across 33 families, with medicinal uses dominating (36% of species), followed by construction materials (13%) and fodder (11%). Diversity indices indicated moderate levels (Shannon-Weiner H'=1.335; Simpson's D=0.421). Critical conservation concerns emerged with 31 species (35%) occurring in single locations and 25 species at critically low densities, indicating high extinction risk. The Climate Vulnerability Index (4.4) demonstrated moderate vulnerability, with strong adaptive capacity (10.4) buffering high plant-based sensitivity (3.8) and moderate climate exposure (2.2). Climate awareness was exceptionally high (91% of respondents), with strong correspondence between women's perceptions and meteorological data validating traditional ecological knowledge systems. The study conclusively demonstrates that climate change significantly impacts plant biodiversity with direct implications for Maasai women's livelihoods. Despite strong traditional knowledge and social capital through cooperatives, communities face climate risks and biodiversity loss that threaten healthcare access, food security, and cultural practices. Key recommendations include establishing community conservancies with women as primary managers, implementing climate-smart plant management integrating traditional and scientific knowledge, strengthening women's cooperatives for economic resilience, developing integrated climate information systems, and creating intergenerational knowledge transfer programs. These findings advance understanding of the climate-biodiversity-gender nexus and inform evidence-based policy interventions for pastoral communities navigating climate uncertainty.

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ABBREVIATIONS AND ACRONYMS

ASALs	Arid and Semi-Arid Lands
CVI	Climate Vulnerability Index
ENSO	El Niño-Southern Oscillation
FGD	Focus Group Discussion
GoK	Government of Kenya
ICPAC	IGAD Climate Prediction and Applications Centre
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IVI	Importance Value Index
KEFRI	Kenya Forestry Research Institute
KMO	Kaiser-Meyer-Olkin
LVI	Livelihood Vulnerability Index
NACOSTI	National Commission for Science, Technology and Innovation
NASA	National Aeronautics and Space Administration
NDC	Nationally Determined Contributions
NGO	Non-Governmental Organization
SPSS	Statistical Package for the Social Sciences
TEK	Traditional Ecological Knowledge
UNDP	United Nations Development Programme
WMO	World Meteorological Organization

OPERATIONAL DEFINITION OF TERMS

Adaptive Capacity: The potential, capability, or ability of a species, ecosystem, or human system to adjust to climate change, moderate potential damage, take advantage of opportunities, or respond to consequences (IPCC, 2014). In this study, it encompasses social capital, traditional knowledge, economic resources, and institutional support available to Maasai women for responding to climate-induced changes.

Climate Change: Long-term shifts in temperatures and weather patterns, primarily caused by human activities such as burning fossil fuels, leading to rising temperatures, altered precipitation patterns, extreme weather events, and disrupted ecosystems (IPCC, 2021).

Climate Vulnerability Index (CVI): A composite measure quantifying the degree to which a system is susceptible to climate change impacts, calculated as the difference between adaptive capacity and the sum of exposure and sensitivity components (Hahn et al., 2009).

Exposure: The nature, magnitude, and rate of climatic and associated environmental changes experienced by a species, ecosystem, or human community, including temperature increases, precipitation variability, and extreme weather events (Dawson et al., 2011; IPCC, 2014).

Hazard: The potential occurrence of a natural or human-induced physical event, trend, or physical impact that may cause loss of life, injury, health impacts, damage to property, infrastructure, livelihoods, ecosystems, and environmental resources (IPCC, 2014).

Livelihood: The means by which people secure the necessities of life, including food, shelter, clothing, and income, through various activities such as farming, fishing, livestock keeping, trade, employment, or combinations thereof—particularly important in discussions about sustainable development and resilience (DFID, 1999).

Plant Species Diversity: The variety and abundance of plant species within a particular area or ecosystem, typically measured using indices such as Shannon-Weiner diversity index and Simpson's diversity index, with higher diversity generally associated with greater ecosystem resilience and productivity.

Sensitivity: The degree to which a system is affected, either adversely or beneficially, by climate variability or change, including direct effects (physiological responses) and indirect effects (through altered resource availability or biotic interactions) (IPCC, 2014).

Traditional Ecological Knowledge (TEK): A cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment (Berkes, 2012).

Transitioning Maasai Pastoralists: Maasai communities undergoing fundamental livelihood transformation from traditional nomadic/semi-nomadic pastoralism toward more sedentary, diversified economic systems, involving spatial settlement, economic diversification, land tenure shifts, and cultural adaptation in response to rangeland fragmentation, restricted mobility, and climatic stress (Fomina et al., 2022; Caravani et al., 2024).

Vulnerability: The degree to which a system; such as a community, ecosystem, or livelihood; is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes, determined by the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, 2014).

Vulnerability Index: A composite measure quantifying the exposure of a population or system to hazards, typically comprising multiple quantitative indicators combined through mathematical formulae to deliver a single numerical result indicating overall vulnerability level.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Climate change represents one of the most pressing global challenges of the 21st century, with disproportionate impacts on vulnerable populations in developing countries. Global temperatures have risen approximately 1.1°C above pre-industrial levels, with projections indicating potential increases of 1.5-2.0°C by 2040 if current emission trajectories continue (IPCC, 2021). This warming drives multiple cascading impacts including altered precipitation patterns, increased frequency and intensity of extreme weather events, sea-level rise, and ecosystem disruption affecting approximately 3.6 billion people currently living in contexts highly vulnerable to climate change (IPCC, 2022).

East Africa experiences particularly severe climate impacts through amplified warming rates, increasing precipitation variability, and more frequent droughts and floods disrupting rain-dependent agriculture and pastoral livelihoods (Gebrechorkos et al., 2023). Kenya's arid and semi-arid lands (ASALs) covering 80% of national territory face acute vulnerability with warming rates of 0.34°C per decade nearly double the global average. The 2010-2011 drought resulted in over 2.5 million livestock deaths and severe food insecurity affecting millions, while the 2016-2017 drought created humanitarian crisis requiring international emergency response (Uhe et al., 2018).

Climate change increasingly threatens plant biodiversity through direct impacts (temperature stress, altered precipitation, extreme events causing mortality) and indirect effects (habitat fragmentation, phenological disruption, altered species interactions). The IPCC (2022) projects that approximately 1 million species face extinction risk globally, with African ecosystems particularly vulnerable due to multiple interacting stressors including climate change, land use change, and unsustainable resource extraction. Plant biodiversity loss carries profound implications for human livelihoods, particularly in rural communities depending on wild plant resources for medicine, food, construction materials, fodder, and cultural practices.

Gender dimensions of climate vulnerability remain critically understudied despite growing recognition that climate impacts prove systematically differentiated by gender. Women in developing countries experience disproportionate climate burdens due to structural inequalities, gender-based divisions of labor assigning women primary responsibility for household water and fuelwood collection, food preparation, and healthcare provision, restricted mobility limiting adaptation options, and limited participation in decision-making processes (UN Women, 2024). Climate change may push up to 158 million more women into poverty by 2050, with women currently experiencing 47.8 million higher food insecurity rates than men globally (UN Women, 2024).

This study focuses on Maasai women in Narok County, Kenya, as emblematic case of climate-biodiversity-gender nexus in African pastoral contexts. Maasai communities depend extensively on plant biodiversity for medicinal treatments (primary healthcare for 70-80% of ailments), construction timber for housing and livestock enclosures, and livestock fodder during critical dry seasons, wild foods supplementing agricultural production, and cultural/ceremonial plants essential for traditional practices and identity maintenance. Women's specialized ecological knowledge and primary resource collection responsibilities create both unique climate vulnerability and essential contributions to community adaptation.

1.2 Statement of the Problem

Narok County experiences accelerating climate changes manifesting through unpredictable weather patterns, increasing temperatures, erratic rainfall, and more frequent extreme events (droughts, floods, storms) disrupting traditional livelihood systems developed under historical climate stability. Over the past 30 years (1990-2020), communities report unprecedented environmental instability affecting plant resource availability, agricultural productivity, livestock health, and water security. Simultaneously, plant biodiversity faces multiple threats including climate-induced mortality, unsustainable harvesting driven by resource scarcity, habitat conversion to agriculture, and disrupted regeneration from altered rainfall patterns.

These climate and biodiversity stresses concentrate disproportionately on Maasai women who bear primary responsibility for collecting medicinal plants, fuelwood, water, and wild foods activities requiring progressively longer distances and time as resources become scarce. Women reported that collection distances doubled or tripled during droughts while critical plant species disappeared entirely, forcing difficult choices between traveling excessive distances, purchasing expensive commercial substitutes, or going without essential resources. Medicinal plant scarcity particularly affects women's healthcare provision responsibilities, construction timber scarcity creates housing inadequacy, and wild food depletion threatens household nutrition during agricultural shortfalls.

Despite documented climate impacts and observed biodiversity changes, systematic scientific assessment integrating climate trend analysis, botanical surveys, livelihood impact assessment, and gender-responsive vulnerability analysis remains lacking for Narok County. Existing studies examine climate trends or biodiversity or gender dimensions in isolation, missing critical interactions where climate drives biodiversity loss which amplifies women's livelihood vulnerability. This knowledge gap constrains development of evidence-based adaptation strategies addressing root causes and supporting most vulnerable populations.

Furthermore, traditional ecological knowledge systems guiding resource management and seasonal planning show signs of disruption under novel climate conditions exceeding historical experience ranges. Elders report that traditional weather forecasting methods "no longer work," seasonal calendars prove unreliable, and plant species appear in unexpected locations or times. Simultaneously, intergenerational knowledge transmission weakens as young people attend schools, migrate to urban areas, and adopt modern lifestyles reducing environmental interaction necessary for experiential learning. This dual knowledge crisis—disruption of existing knowledge and failure to transmit knowledge to younger generations—threatens elimination of irreplaceable intellectual capital within one generation.

1.3 Justification for the Study

This study addresses critical research and policy gaps at the intersection of climate change, biodiversity conservation, and gender equity in pastoral contexts. Several factors justify the research focus:

While extensive literature examines climate impacts on agriculture or biodiversity conservation or gender inequality separately, integrated analysis of these interconnected dimensions remains rare. This study provides holistic assessment revealing how climate change drives biodiversity loss which amplifies gendered livelihood vulnerabilities—understanding essential for developing effective integrated interventions. Maasai women face systematic disadvantages through restricted mobility limiting adaptation options (cultural norms constrain women's independent movement), limited decision-making authority over household resources despite primary management responsibilities, unequal resource access including land ownership, credit, and extension services, and disproportionate labor burdens for household provisioning intensifying under climate stress. Yet quantitative documentation of specific vulnerability pathways, magnitudes, and consequences remains limited, constraining targeted support.

The study provides rare 30-year (1990-2020) climate trend analysis for Narok County, meeting WMO standards for climate change detection while covering period of accelerated anthropogenic warming. This baseline enables distinguishing anthropogenic trends from natural variability and provides reference for future monitoring. Systematic ethnobotanical surveys documenting species diversity, traditional uses, conservation status, and climate sensitivities provide critical information for biodiversity conservation planning and sustainable resource management. The spatial distribution analysis identifying extinction hotspots and critically rare species informs strategic conservation prioritization. The systematic documentation of traditional ecological knowledge including plant nomenclature, use protocols, climate indicators, and seasonal calendars preserves invaluable intellectual capital threatened by disruption and erosion. This documentation serves both immediate policy needs and long-term cultural heritage preservation.

The explicit focus on women's knowledge, vulnerabilities, and adaptive strategies generates evidence supporting gender-responsive climate adaptation policies and programs. Rather than treating households as homogeneous units, the study reveals gender-differentiated impacts requiring targeted interventions. Findings directly inform multiple policy domains including Kenya's National Climate Change Action Plan, county-level climate adaptation strategies, biodiversity conservation under Kenya

Wildlife Service and Kenya Forest Service, gender mainstreaming in climate policy, and integration of traditional knowledge into natural resource management.

1.4 Research Objectives

1.4.1 Main Objective

To analyze the impacts of climate change on plant biodiversity and Maasai women's livelihoods in Narok County, Kenya, and assess community vulnerability and adaptive capacity.

1.4.2 Specific Objectives

1. To analyze temperature and precipitation trends (1990-2020) in Narok County using Mann-Kendall tests and Sen's slope estimator.
2. To document plant species diversity, traditional uses, and spatial distribution across 8 locations, targeting minimum 50 species.
3. To calculate Climate Vulnerability Index for 100 Maasai women households integrating exposure, sensitivity, and adaptive capacity.
4. To assess climate change awareness through knowledge levels, perception accuracy versus measured trends, and information sources accessed.

1.5 Research Questions

1. What are the temperature and precipitation trends (1990-2020) in Narok County, and how do they compare with community perceptions?
2. What is the plant species diversity, traditional uses, and conservation status of species critical for women's livelihoods?
3. What is the climate vulnerability level for Maasai women households, and how does it vary across households?

4. What climate information sources do women access, and how accurate are traditional observations compared to meteorological data?

1.6 Scope and Limitations

The study focuses geographically on Narok County, specifically four sub-counties (Narok South, Narok North, Trans-Mara East, Trans-Mara West) representing diverse ecological and socioeconomic contexts within the county. Temporally, climate analysis covers 1990-2020 (30 years meeting WMO climate detection standards), while household surveys and botanical assessments occurred August-October 2024,.

The achieved sample size of 100 households (26% of calculated target of 390) due to resource and accessibility constraints yields approximately 9.5% margin of error at 95% confidence level—acceptable for exploratory research but limiting statistical power for detecting small effects. The single-season botanical survey potentially missed species visible only during other seasons, though year-round surveys proved infeasible within constraints. Findings reflect Maasai-specific contexts and may not generalize directly to other ethnic groups or pastoral systems without appropriate contextual adaptation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter provides comprehensive review of literature relevant to the study's four specific objectives: climate change trends and patterns, plant biodiversity and gender-differentiated dependencies, vulnerability and adaptive capacity to climate-induced changes, and women's knowledge and awareness of climate change. The review establishes theoretical foundations for understanding complex relationships between climate change, biodiversity, and gender dynamics in pastoral communities, progressing systematically from global patterns to regional contexts to local applications. Particular emphasis is placed on identifying research gaps that this study addresses, situating the research within broader scientific discourse while highlighting unique contributions to knowledge.

2.2 Climate Change Phenomenon and Trends

2.2.1 Global Climate Change Context

Climate change represents long-term alteration in average weather patterns driven primarily by human activities, particularly fossil fuel combustion, which increases concentrations of heat-trapping greenhouse gases in Earth's atmosphere (IPCC, 2021; Malti et al., 2020). The scientific consensus, established through multiple independent lines of evidence and affirmed by every major scientific organization globally, confirms that observed warming since the mid-20th century is unequivocally caused by human activities, primarily carbon dioxide emissions from fossil fuel burning, deforestation, and industrial processes (IPCC, 2023).

Global average temperature has increased by approximately 1.1°C above pre-industrial levels (1850-1900) during the 2011-2020 period, with current warming rates exceeding

0.2°C per decade in many regions (IPCC, 2023). The year 2024 was confirmed as the warmest on record by the World Meteorological Organization (2025), continuing an alarming trend where each of the past eight years has ranked among the ten warmest in the instrumental record extending back to 1850. This warming trajectory proceeds at a rate unprecedented over millennia, with paleoclimate reconstructions indicating that current warming rates exceed anything experienced during the past 2,000 years (Hansen et al., 2016).

Climate change manifests not merely as gradual warming but through fundamental alterations in Earth's climate system including shifts in precipitation patterns with some regions becoming wetter while others experience intensified drying, increased frequency and intensity of extreme weather events including heatwaves, droughts, floods, and tropical cyclones, accelerated melting of glaciers and polar ice caps contributing to sea level rise, ocean warming and acidification threatening marine ecosystems, and disruption of seasonal timing affecting plant phenology, animal migration, and agricultural calendars (IPCC, 2021). These changes create cascading impacts across natural and human systems, with consequences extending far beyond simple temperature increases.

The impacts of climate change fall disproportionately on vulnerable populations, creating fundamental questions of climate justice. Approximately 3.6 billion people currently inhabit regions characterized by high climate vulnerability, where human wellbeing and ecosystem health are inextricably linked and adaptive capacity is constrained by poverty, limited infrastructure, and governance challenges (IPCC, 2022). Climate-related mortality from extreme weather events is fifteen times higher in highly vulnerable regions compared to areas with low vulnerability, reflecting differential capacity to prepare for, respond to, and recover from climate impacts (UN

Women, 2025). Indigenous communities, smallholder farmers, coastal populations, and economically marginalized households bear disproportionate costs of environmental changes despite contributing minimally to cumulative greenhouse gas emissions—creating profound inequities between those causing climate change and those suffering its consequences.

2.2.2 Regional Climate Trends in East Africa

East Africa has experienced significant climatic variability over the past three decades with profound implications for temperature and precipitation patterns, ecosystem functioning, and human livelihoods (Nicholson, 2017). The region exemplifies complex climate dynamics where global warming trends interact with regional climate systems including the El Niño-Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), and local land-atmosphere feedbacks to produce heterogeneous patterns of change varying substantially across space and time.

Comprehensive analysis by Gebrechorkos et al. (2023) demonstrates that precipitation, precipitation extremes, and temperature will all increase across large parts of East Africa during the 21st century under multiple emission scenarios. However, these increases manifest unevenly with critical implications for water resources, agriculture, and ecosystem health. Hydrological extremes both droughts and floods are projected to intensify, creating whiplash conditions where periods of severe water scarcity alternate with destructive flooding, challenging adaptation strategies designed for more stable conditions (Gebrechorkos et al., 2023).

Most climate models predict increased total annual precipitation for the region, elevating flood risks particularly during the short rains season (October to December), with the frequency of extremely wet short rains expected to increase substantially

(ICPAC, 2024). However, this increased total precipitation does not necessarily translate to improved water security, as rainfall often arrives in intense storms that generate runoff rather than soil infiltration, while lengthened dry periods between rainfall events intensify drought stress for both plants and water supplies (ICPAC, 2024). Temperature trends show more consistent patterns of increase across the region. The average surface temperature across Africa in 2024 was approximately 0.86°C above the 1991-2020 long-term average, with some subregions experiencing increases exceeding 1.28°C (World Meteorological Organization, 2025). Eastern Africa has experienced warming rates generally exceeding global averages, with particular intensification in semi-arid and arid regions where reduced vegetation cover and altered land-atmosphere energy exchanges amplify warming trends (Nicholson, 2017).

These changes carry profound implications for pastoral communities who depend heavily on predictable seasonal patterns for livestock management, agricultural timing, and natural resource utilization (Thornton et al., 2009). The disruption of historical climate patterns undermines traditional ecological knowledge developed over generations under different climate conditions, potentially rendering ancestral strategies for resource management ineffective or even counterproductive under novel climate regimes (Thornton et al., 2009).

2.2.3 Climate Trends in Kenya and Narok County

Kenya has experienced dramatic climatic changes with particularly severe impacts on arid and semi-arid lands (ASALs) that comprise approximately 70% of the country's land area and support significant pastoral and agro-pastoral populations (CSIS, 2025). National average temperatures rose by approximately 1.0°C between 1960 and 2003, while arid regions experienced warming of 1.5°C over the same period, substantially exceeding national averages and reflecting enhanced warming typical of drylands globally (Jaetzold & Shisanya, 2009).

More recent analysis indicates temperature increases of approximately 0.34°C per decade over three decades from 1990-2020, with projections suggesting temperatures could rise by an additional 1.5 to 2°C by 2050 under high greenhouse gas emission scenarios (CSIS, 2025). If global emissions continue along current trajectories, some models project temperature increases exceeding 3°C by 2100 for parts of Kenya, fundamentally transforming ecosystems and rendering current livelihood strategies untenable without radical adaptation (CSIS, 2025). The areas most severely affected by climate change include counties in northern and eastern Kenya: Garissa, Isiolo, Kajiado, Turkana, Kitui, Mandera, Marsabit, Laikipia, Samburu, Tana River, and Wajir (UN Africa Renewal, 2024). The National Drought Management Authority categorizes these regions as part of the "alarm stage" requiring emergency humanitarian interventions due to severe drought impacts on food security, water availability, and livestock survival. Recent droughts spanning 2020-2023 resulted in loss of 2.5 million head of livestock, representing not merely economic losses but fundamental threats to pastoral identity, cultural continuity, and food security (Metuy, 2024). The remaining 10 million livestock in drylands suffer from inadequate pasture and water availability, with cascading effects on milk production, household nutrition, and income generation (Metuy, 2024).

Kenya's vulnerability is particularly pronounced due to economic reliance on rain-fed agriculture, which employs 40% of the total population and over 70% of the rural population, creating direct exposure to climate-driven changes in precipitation patterns and growing season characteristics (Trisos et al., 2022). Rising temperatures and erratic rainfall undermine livelihoods dependent on rain-fed systems while also affecting water resources, hydroelectric power generation, tourism, and other economic sectors (CSIS, 2025).

Narok County, located in Kenya's Great Rift Valley region and covering approximately 17,944 square kilometers, has experienced climate variability consistent with broader East African trends (Kimani et al., 2018). The county falls within Kenya's arid and semi-arid lands classification, characterized by semi-arid to sub-humid climate with bimodal rainfall patterns occurring during long rains (March-May) and short rains (October-December). Historical climate records document high inter-annual and decadal variability in both temperature and precipitation, creating challenging conditions for rain-dependent livelihoods (Silvestri et al., 2012).

The region's location within the Great Rift Valley creates complex topographic influences on local climate, with elevation ranges from approximately 1,500 meters to over 3,000 meters generating microclimatic variation and influencing species distributions, agricultural potential, and resource availability. Climate projections for Narok County suggest continued warming and increased rainfall variability with potentially intensified extreme events including both droughts and floods, carrying significant implications for pastoral livelihoods, biodiversity conservation, and food security (Rojas-Downing et al., 2017).

2.3 Plant Biodiversity and Ecosystem Services

2.3.1 Global Biodiversity Patterns and Threats

Plant diversity represents a critical component of terrestrial biodiversity globally, sustaining ecosystem structure and functions while reflecting species composition, evolutionary history, and community organization shaped by millions of years of adaptation (IPCC, 2022). Vascular plants comprising approximately 300,000-400,000 described species globally, provide foundation for terrestrial ecosystems by converting solar energy into biomass through photosynthesis, creating habitat structure utilized by countless animal species, regulating water and nutrient cycles, stabilizing soils against erosion, and moderating local and regional climate through evapotranspiration and carbon sequestration (Jenkins et al., 2021).

The loss of plant diversity results in severe consequences extending far beyond simple species extinctions to include ecological imbalance as key functional groups disappear from communities, depletion of biological resources including genetic diversity essential for crop improvement and pharmaceutical development, environmental degradation through disrupted nutrient cycling and soil formation, decreased primary productivity reducing capacity to support food webs, and compromised food security as agricultural biodiversity declines and ecosystem services supporting production deteriorate (Habibullah et al., 2022).

Global biodiversity faces unprecedented threats from multiple, interacting pressures. The primary drivers of biodiversity loss include habitat destruction and degradation through agricultural expansion, urban development, logging, and infrastructure development that fragments landscapes and eliminates natural ecosystems; overexploitation through unsustainable harvesting of wild plants for timber, fuelwood, medicinal compounds, and other products; invasive species that outcompete, prey upon, or spread diseases to native flora; pollution including nitrogen deposition, pesticides, and heavy metals that alter ecosystem functioning; and climate change itself, which drives range shifts, phenological disruption, and extinction through mechanisms operating across multiple spatial and temporal scales (IPCC, 2022).

Recent global evidence from 115 countries indicates that temperature increases, precipitation changes, and natural disaster occurrences all significantly contribute to biodiversity loss through pathways including physiological stress exceeding species' thermal tolerance limits, hydrological changes affecting water-dependent species and wetland ecosystems, extreme weather events causing direct mortality and habitat destruction, phenological disruption disconnecting plant-pollinator and plant-disperser mutualisms, range shifts forcing species into smaller or marginal habitats, and increased disease and pest pressures as climate change alters host-pathogen dynamics (Rahman et al., 2024).

Current projections indicate that climate change could become the dominant driver of biodiversity decline by mid-century if emissions continue along high pathways, potentially surpassing habitat destruction as the primary threat to species persistence (Pereira et al., 2024). Biodiversity declines from combined climate and land use change could lead to global loss of between 7.44-103.14 PgC in vegetation carbon storage, representing massive carbon release that would further accelerate climate change through positive feedback loops linking biodiversity loss and climate change in reinforcing cycles (Pereira et al., 2024).

Approximately one million plant and animal species currently face extinction risk globally—representing roughly one-eighth of total described species—with extinction rates estimated to be tens to hundreds of times higher than background rates documented in the fossil record (IPCC, 2022). For many species, extinction risk stems not from single threats but from synergistic interactions among multiple pressures that create cumulative impacts exceeding simple additive effects.

2.3.2 African Plant Biodiversity and Hotspots

Africa hosts exceptional plant biodiversity reflecting the continent's vast size, topographic and climatic diversity, and complex evolutionary and biogeographic history. The continent contains eight of the 36 globally recognized biodiversity hotspots areas supporting at least 1,500 endemic vascular plant species while having lost at least 70% of primary vegetation including the Cape Floristic Region, Succulent Karoo, Coastal Forests of Eastern Africa, Eastern Afromontane, Guinean Forests, Horn of Africa, Madagascar and Indian Ocean Islands, and Maputaland-Pondoland-Albany (White & Case, 2023).

These hotspots represent global conservation priorities due to exceptional species richness and endemism combined with severe threats from habitat loss, with many containing thousands of plant species found nowhere else on Earth. The Cape Floristic Region alone harbors approximately 9,000 plant species with 70% endemic to the region, representing one of the world's most extraordinary concentrations of plant diversity (White & Case, 2023). Madagascar hosts over 12,000 plant species with endemism rates exceeding 80%, creating unique flora shaped by millions of years of isolation following separation from Africa and India.

However, biodiversity extends far beyond recognized hotspots. Across sub-Saharan Africa, diverse ecosystems support rich plant communities adapted to local environmental conditions including tropical rainforests in the Congo Basin and West Africa, miombo woodlands covering vast areas of southern and eastern Africa, Afromontane forests on isolated mountain ranges, savanna ecosystems across the Sahel and southern Africa, semi-arid shrublands and grasslands, coastal mangrove forests, and specialized habitats such as inselbergs and wetlands (Osewe et al., 2024).

Current projections suggest alarming biodiversity losses across the continent under climate change scenarios. By 2100, more than half of Africa's bird and mammal species could be lost if emissions continue along high pathways, while productivity of Africa's lakes could decline by 20-30% due to warming and altered hydrology (Chapman et al., 2022). Plant biodiversity faces similar threats, with range contractions, extirpations, and extinctions projected to accelerate as climate velocities exceed species' migration capacities and suitable habitat shrinks or disappears entirely (Sintayehu, 2018).

Agricultural practices contribute significantly to biodiversity deterioration through conversion of natural ecosystems for crop production that eliminates native vegetation, carbon emissions from deforestation and land use change, and unsustainable farming practices that degrade soil, diminish land productivity, and reduce landscape-scale habitat availability (FP Analytics, 2024). Paradoxically, agricultural systems themselves depend heavily on biodiversity, with over 75% of food crop varieties worldwide requiring animal pollinators for reproduction—creating dangerous feedback loops where agricultural expansion threatens the biodiversity upon which agriculture depends (FP Analytics, 2024).

2.3.3 East African Flora and Ecosystem Services

The East African region hosts diverse forest ecosystems, woodlands, shrublands, and grasslands that provide essential resources benefiting livelihoods both directly through harvested products and indirectly through ecosystem services (Osewe et al., 2024). These ecosystems include coastal mangrove forests providing critical nursery habitat for fisheries, protection against coastal erosion and storm surge, and carbon sequestration at rates exceeding terrestrial forests; highland montane forests on Mount Kenya, Mount Kilimanjaro, and other peaks supplying watershed protection, water regulation, and unique endemic species; miombo and mopane woodlands covering vast areas supporting diverse wildlife and providing timber, fuelwood, wild foods, and medicinal plants; and acacia-dominated savanna ecosystems characteristic of pastoral rangelands offering browse and grazing for livestock and wildlife.

These ecosystems provide multiple ecosystem services essential for human wellbeing including provisioning services such as timber, fuelwood, construction materials, wild foods, medicinal plants, and livestock fodder; regulating services including climate regulation through carbon sequestration, water regulation and purification, soil formation and erosion control, and pollination; cultural services encompassing spiritual values, recreational opportunities, aesthetic appreciation, and cultural identity; and supporting services such as nutrient cycling, primary production, and habitat provision that underpin all other services (Osewe et al., 2024).

Systematic reviews of forest ecosystem services in East Africa reveal extensive documentation of provisioning services, particularly timber, fuelwood, and non-timber forest products, reflecting their direct economic importance and visibility to resource users (Osewe et al., 2024). However, regulating and supporting services receive less research attention despite their fundamental importance for sustaining human wellbeing over longer timescales. This research bias toward easily quantified provisioning services potentially leads to undervaluation of less visible but equally essential ecosystem functions.

Agroforestry represents a powerful practice for sustainable and regenerative intensification in East African landscapes, promoting multifunctionality that delivers ecological functions contributing to livelihoods, land productivity, biodiversity conservation, and climate regulation simultaneously (Syampungani et al., 2023). Research indicates that the main livelihood benefits from agroforestry practices in East

Africa include fodder provision for livestock nutrition (reported in over 70 publications), food production through fruits, nuts, and vegetables (63 publications), firewood supply for household energy (56 publications), and income generation through sale of agroforestry products (40 publications)—demonstrating multiple pathways through which tree integration enhances agricultural system productivity and resilience (Syampungani et al., 2023).

However, tree cover across many East African landscapes continues declining due to agricultural expansion, unsustainable harvesting for fuelwood and charcoal, and increasing human population density creating greater pressure on land resources. This deforestation and degradation threatens not only biodiversity but also the ecosystem services upon which rural livelihoods depend, creating potential for poverty traps where environmental degradation and economic marginalization reinforce each other in negative spirals (Syampungani et al., 2023).

2.3.4 Kenyan Plant Biodiversity Resources

Kenya has documented exceptionally high plant biodiversity given its relatively small geographic area, with 4,623 vascular plant species within 1,387 genera, 766 species of bryophytes (mosses and liverworts), 511 fern species, and 2,071 species of fungi and lichens, representing significant biodiversity wealth that supports ecosystem functioning and human livelihoods (GoK, 2018). This diversity reflects Kenya's position spanning the equator with elevational ranges from sea level to over 5,000 meters on Mount Kenya, creating extraordinary habitat diversity from coastal mangrove forests through lowland savannas and woodlands to Afromontane forests and alpine vegetation.

However, this biodiversity faces multiple threats. The Government of Kenya's Sixth National Report to the Convention on Biological Diversity (GoK, 2020) documents continued habitat loss and degradation from agricultural expansion, urbanization, infrastructure development, and unsustainable resource extraction. Approximately 30% of Kenya's land area is designated as protected areas including national parks, national reserves, forest reserves, and marine protected areas, yet many protected areas suffer from inadequate management, insufficient funding, human-wildlife conflict, and encroachment pressures that compromise their conservation effectiveness.

Climate change projections for Kenya indicate major shifts in vegetation patterns by mid-century, with some species experiencing range contractions or extirpations while others may expand into newly suitable areas (Ribeiro et al., 2023). Particularly concerning are projected impacts on highland forest ecosystems that provide critical watershed services for agriculture, hydropower generation, and domestic water supplies serving millions of people. As temperatures warm, highland species may experience shrinking suitable habitat as they are pushed upward to higher elevations, eventually running out of mountain to colonize (Ribeiro et al., 2023).

Kenya's National Biodiversity Strategy and Action Plan 2019-2030 recognizes the critical importance of integrating biodiversity conservation with climate change adaptation and sustainable development (GoK, 2018). However, implementation faces challenges including limited financial resources, competing land use priorities, inadequate enforcement of environmental regulations, and insufficient integration of biodiversity considerations into sectoral planning for agriculture, energy, infrastructure, and other development areas.

2.4 Gender Dimensions of Plant Resource Dependence

2.4.1 Women's Roles in Natural Resource Management Globally

Women play critical yet often under recognized roles in natural resource management globally, particularly in rural areas of developing countries where livelihoods depend heavily on agriculture, forestry, fisheries, and collection of wild resources (Rocheleau et al., 1996). Gender-based divisions of labor common across many cultures assign specific resource management responsibilities to women including collection of fuelwood for household cooking and heating, gathering of wild edible plants for household nutrition and food security, harvesting medicinal plants for healthcare, fetching water for domestic use, collection of fodder for livestock, and gathering of materials for handicrafts and household items (Rocheleau et al., 1996).

These responsibilities create intimate relationships between women and their local environments, generating detailed traditional ecological knowledge about plant identification, seasonal availability, harvest timing, processing techniques, and sustainable collection practices accumulated through daily resource interactions over lifetimes. This knowledge represents invaluable intellectual capital supporting household food security, healthcare, and income generation while also providing foundation for biodiversity conservation and sustainable resource management (Berkes, 2012).

However, women's resource management knowledge and contributions often remain invisible to policy makers, development practitioners, and researchers, resulting in their systematic exclusion from decision-making processes, development programs, and research initiatives related to natural resource management. This exclusion has multiple negative consequences including ineffective policies and programs that fail to address women's specific needs and constraints, lost opportunities to draw upon women's environmental knowledge for conservation and adaptation planning, perpetuation of gender inequalities that limit women's access to resources and economic opportunities, and undermined sustainability of resource management as those with daily management responsibilities lack voice in governance (Rocheleau et al., 1996). Research by the World Bank (2014) indicates that if women worldwide had the same access to productive resources as men, they could increase yields on their farms by 20-30% and raise total agricultural output by 2.5-4%, potentially lifting 100 to 150 million people out of hunger. This estimate underscores the massive untapped potential of supporting women's agricultural and natural resource management activities through improved access to land, credit, inputs, training, and markets. Yet despite recognition of these benefits, gender gaps in resource access persist across most developing countries, constraining both agricultural productivity and women's empowerment.

2.4.2 Gender and Plant Resource Utilization in Africa

Across sub-Saharan Africa, women's dependence on plant biodiversity is particularly pronounced due to their traditional roles in food provision, healthcare, and household management combined with limited access to modern alternatives (Traditional Knowledge World Bank, 2019). Rural women commonly engage in collection of wild edible plants including leafy vegetables, fruits, tubers, and seeds that supplement household nutrition, particularly during hungry seasons when cultivated food supplies dwindle; medicinal plants for treating common ailments in contexts where access to modern healthcare remains limited or unaffordable; fuelwood and charcoal for cooking in absence of electricity or other modern energy sources; construction materials for housing, fencing, and household infrastructure; and income-generating products including fibers for basket weaving, dyes for cloth production, and edible or medicinal plants for sale in local markets (Traditional Knowledge World Bank, 2019).

Community demands for survival and livelihood are frequently influenced by biodiversity utilization patterns, with rural populations engaging in activities such as hunting, fishing, charcoal production, firewood collection, and handicraft material gathering that directly depend on local plant and animal diversity (Traditional Knowledge World Bank, 2019). Women often predominate in collection of non-timber forest products, creating economic dependencies on biodiversity that make them particularly vulnerable to environmental degradation and climate change impacts.

The United Nations Development Programme (2024) emphasizes that women are crucial custodians of indigenous knowledge passed down through generations, often the first to notice declining resources and environmental hazards, and leading efforts to find solutions for their communities. This recognition challenges historical narratives that portrayed women solely as resource users and environmental degraders, instead acknowledging their roles as environmental stewards, knowledge holders, and change agents with capabilities essential for sustainable resource management and climate adaptation.

However, contemporary research reveals complex patterns in women's participation in biodiversity-dependent enterprises. While agroforestry offers substantial potential benefits to women through diversified income sources, improved nutrition, and enhanced resource availability, women's participation remains low in enterprises considered men's domain such as timber production and high-value tree crops, while they predominate in enterprises with little commercial value such as collection of indigenous fruits and vegetables (Kiptot & Franzel, 2012). This pattern reflects broader gender inequalities in access to markets, credit, training, and land that constrain women's ability to benefit economically from agroforestry even when they perform majority of labor in tree planting and management.

Recent studies demonstrate that greater women's empowerment is associated with higher farm-level crop diversity among low-income agricultural households, suggesting potential for enhancing food system resilience through women's empowerment interventions that increase their control over agricultural decisions and resources (Galiè et al., 2023). Empowered women tend to prioritize crop diversity for household nutritional needs and risk management rather than focusing solely on commercial production, creating beneficial linkages between gender equity and agrobiodiversity conservation.

2.4.3 Maasai Women and Plant Biodiversity Dependencies

Among Maasai communities, women's dependence on plant biodiversity is shaped by specific cultural practices, gender roles, and livelihood systems characteristic of pastoral societies. The Maasai have historically practiced semi-nomadic pastoralism centered on livestock keeping, particularly cattle, goats, and sheep that provide milk, meat, and blood for household nutrition along with income from livestock sales (Nankaya et al., 2019). However, this pastoral system has always been supplemented by utilization of wild plant resources, particularly during dry seasons when livestock productivity declines and households require alternative food sources.

Maasai women bear primary responsibility for multiple household tasks that create direct dependencies on plant resources including collection of fuelwood for cooking, water collection from increasingly distant sources during droughts, wild vegetable gathering to supplement household nutrition, medicinal plant harvesting for treating human and livestock ailments, construction material collection for hut building and maintenance, and ceremonial plant preparation for traditional rituals and practices (Nankaya et al., 2019).

Systematic documentation of medicinal plants used by Maasai communities in Kenya has identified numerous species utilized for diverse therapeutic purposes. Nankaya et al. (2019) documented traditional medicinal plants of Kenyan Maasai, revealing sophisticated pharmacopeia based on generations of observation and experimentation. Plant remedies address wide range of health conditions including digestive disorders, respiratory infections, skin conditions, reproductive health, malaria, livestock diseases, and spiritual/psychological ailments, demonstrating comprehensive traditional healthcare system that operates largely independent of modern medical services.

Similar research by Kigen et al. (2019) in Narok County specifically documented ethnomedical plants used by traditional healers, identifying numerous species with detailed preparation methods, administration routes, and therapeutic applications. This study emphasized the critical role of elderly women and traditional healers as knowledge custodians who maintain elaborate understanding of plant properties, seasonal collection timing, sustainable harvesting practices, and processing techniques essential for therapeutic efficacy.

However, Maasai women's plant resource dependencies occur within context of significant gender inequalities that limit their adaptive capacity and economic opportunities. Women typically lack independent land ownership, with land traditionally controlled by male household heads or clan leaders. They have limited decision-making authority in household and community affairs, with major decisions about resource use, livestock management, and household economy typically made by men. Access to education has historically been limited, with girls' school enrollment rates lower than boys' and early marriage often terminating educational opportunities. Mobility restrictions confine women to homesteads while men engage in livestock herding and market activities that expose them to information and economic opportunities. Financial services access remains constrained, with women having difficulty obtaining credit without male co-signers and limited ability to own assets that could serve as collateral (UNDP, 2024). These structural inequalities create particular vulnerabilities when climate change threatens plant resources upon which women depend for household provisioning, healthcare, and cultural practices, while simultaneously limiting their capacity to adapt through alternative livelihood strategies, technology adoption, or participation in formal adaptation programs.

2.5 Climate Change Impacts on Biodiversity and Livelihoods

2.5.1 Global Climate-Biodiversity Interactions

The Intergovernmental Panel on Climate Change (2022) identifies biodiversity loss and degradation, ecosystem destruction, and ecosystem transformation as major hazards for every region as a result of global warming, with impacts intensifying with each degree of temperature increase above pre-industrial levels. Climate change affects biodiversity through multiple, interacting mechanisms operating across spatial scales from individual organisms to ecosystems and temporal scales from immediate physiological responses to evolutionary adaptations over generations. Direct physiological impacts include thermal stress when temperatures exceed species' tolerance limits, disrupting cellular functions, reproduction, and survival; water stress as altered precipitation patterns and increased evaporative demand create drought conditions affecting plant growth and survival; phenological disruption where earlier spring warming causes premature leaf-out, flowering, or migration that may mismatch with pollinators, seed dispersers, or food resources; and extreme event mortality from heatwaves, droughts, floods, fires, and storms that cause immediate die-offs of vulnerable individuals or populations (IPCC, 2022).

Indirect impacts operate through altered species interactions including disrupted pollination when plants and pollinators respond differently to climate cues; modified herbivory patterns as plant defenses change or herbivore populations shift; altered competitive dynamics where some species gain advantages while others decline; and changed disease dynamics as pathogens, hosts, and environmental conditions affecting transmission all respond to climate shifts (Sintayehu, 2018). These indirect effects can cascade through ecosystems, creating community-level reorganizations that fundamentally alter ecosystem structure and function.

Range shifts represent major biodiversity response to climate change, with species moving pole ward or upward in elevation tracking suitable climate conditions as isotherms migrate. However, range shift capacity varies greatly among species depending on dispersal abilities, habitat availability, and physiological tolerances. Many plant species, particularly those with limited dispersal, may be unable to track shifting climate at rates necessary to avoid local extinction. Species confined to mountaintops, islands, or isolated habitat fragments face particular extinction risk as suitable climate space disappears or becomes unreachable (Eigenbrod et al., 2015).

Climate change has resulted in widespread local population extinctions of both flora and fauna documented across all continents and biomes. Marine ecosystems face intensifying impacts from increased marine heatwave intensity, frequency, and duration; ocean warming affecting species distributions and fishery productivity; and ocean acidification reducing calcification rates for corals, shellfish, and other calcifying organisms with cascading effects through marine food webs (IPCC, 2023).

Global food systems contribute to biodiversity deterioration while simultaneously depending on biodiversity for functioning, creating concerning feedback dynamics.

Agricultural expansion drives conversion of natural ecosystems, causing direct habitat loss for native species. Carbon emissions from agriculture and associated land use changes contribute to climate warming. Unsustainable farming practices degrade soil, diminish land productivity, and reduce landscape-scale habitat availability. Yet over 75% of food crop varieties worldwide depend on animal pollinators for reproduction, making agriculture fundamentally dependent on biodiversity it simultaneously threatens (FP Analytics, 2024).

2.5.2 Climate Impacts on African Ecosystems

African ecosystems face particularly severe climate change impacts due to high baseline temperatures approaching physiological limits for many species, precipitation regimes already characterized by high variability making further variability especially disruptive, socioeconomic vulnerabilities that constrain adaptation capacity, and limited resources for conservation and climate adaptation interventions (Chapman et al., 2022).

Projections suggest alarming biodiversity losses across the continent. By 2100, more than half of Africa's bird and mammal species could be lost under high emission scenarios, representing catastrophic ecosystem simplification and loss of evolutionary heritage accumulated over millions of years (Chapman et al., 2022). Lake productivity could decline by 20-30% due to warming waters, altered mixing regimes, and changed nutrient cycling, threatening both biodiversity and fisheries that provide protein for millions of people (Chapman et al., 2022).

Plant biodiversity faces multiple climate-related pressures across African ecosystems. In savanna systems, woody plant encroachment is occurring widely across three continents including extensive areas of Africa, where increased CO_2 levels, altered fire regimes, and herbivore population changes favor woody species over grasses, transforming ecosystem structure and reducing pastoral value (Stevens et al., 2017). Conversely, some forest ecosystems experience increased tree mortality during severe droughts, with potential for forest-savanna transitions in areas experiencing intensified dry seasons.

Climate change threatens major woody species and ecosystem services provision across southern Africa through mechanisms including drought-induced mortality, fire regime changes, and altered regeneration patterns (Kapuka et al., 2022). Species distribution models project substantial range contractions for many valuable timber and fruit trees, threatening both biodiversity and livelihoods dependent on these resources. Protected areas may become less effective as climate zones shift, with species' suitable habitat moving outside current reserve boundaries (Kapuka et al., 2022). Medicinal plant distributions show particular sensitivity to climate change, with potential impacts on bioactive compound profiles even when species persist in altered environments (Alum et al., 2024). Rising temperatures and altered precipitation can change secondary metabolite production affecting plants' therapeutic properties, potentially reducing pharmaceutical efficacy. This represents dual vulnerability through both species loss and reduced quality of remaining populations with serious implications for communities depending on traditional medicine.

Invasive plant species may benefit from climate change through several mechanisms. Climate change can expand suitable habitat for certain invasive species while native species decline, reduced competitive pressure as native vegetation deteriorates, and altered disturbance regimes creating invasion opportunities. Research on invasive cactus species in Pakistan found that extreme climate variability favored *Opuntia stricta* proliferation, with droughts enabling it to outcompete less heat-tolerant native plants while major flooding facilitated widespread dispersal (Khan et al., 2023). Similar dynamics may operate in African drylands, potentially accelerating replacement of native vegetation by invasive species with severe consequences for biodiversity and livelihoods.

2.5.3 Gendered Vulnerability to Climate Change

Extensive literature provides substantial evidence that men and women experience climate change differently, with impacts and susceptibility being systematically differentiated by gender through social roles, access to resources, decision-making authority, and cultural norms (Gender & Climate Alliance, 2016). Research by Adeola et al. (2024) confirms that women are particularly vulnerable to climate change challenges due to cultural norms, inequalities in gender roles, and socioeconomic marginalization across multiple dimensions.

Current projections paint worrying picture for women's climate vulnerability. UN Women (2024) reports that by 2050, climate change may push up to 158 million more women and girls into poverty globally, while currently 47.8 million more women face food insecurity and hunger compared to men. These disparities reflect underlying gender inequalities that concentrate climate impacts on women while limiting their adaptive capacity. A 2024 global study found approximately linear association between gender equality and climate adaptation, with each 1% increase in gender equality associated with 0.6% increase in climate adaptation scores, suggesting that addressing gender inequality represents not merely social justice imperative but practical necessity for effective climate response (Pinho-Gomes & Woodward, 2024).

Multiple factors contribute to gender-based climate change vulnerability across African contexts. Women's reliance on men for financial support increases as climate change affects agricultural productivity and reduces earning capacity of female farmers who typically cultivate smaller, more marginal plots with less access to irrigation, improved seeds, fertilizers, and mechanization (Abiyot et al., 2019). Unequal distribution of economic power between men and women represents major factor contributing to patriarchal oppression and increased susceptibility to climate shocks, as women lack financial buffers necessary to weather crop failures, livestock losses, or health emergencies (Adeola et al., 2024).

Studies reveal that the United Nations estimates 80% of those displaced by climate change are women, with restrictions on their economic, sociocultural, and literal mobility making them particularly vulnerable to displacement while simultaneously constraining their ability to benefit from migration as adaptive strategy (Harvard International Review, 2025). When households migrate in response to climate stress, women often face increased domestic violence, sexual exploitation, and family separation, while lacking legal protections or support services in displacement contexts.

Contemporary research highlights that women remain minority among those making high-level decisions in environmental policy fields, holding only 15% of 712 environmental sector minister positions globally as of 2020 (CLARE Programme, 2024). This underrepresentation means climate policies and adaptation programs often fail to address women's specific vulnerabilities, priorities, and knowledge, resulting in interventions that may inadvertently worsen gender inequalities or miss opportunities to build on women's adaptive capacities.

Climate change impacts on women extend across multiple domains including health vulnerabilities from increased disease burdens (malaria, waterborne diseases), malnutrition affecting both women and children, complications during pregnancy and childbirth, and mental health impacts from chronic stress; livelihood disruptions from reduced agricultural productivity, increased labor burdens for resource collection, loss of income-generating activities, and erosion of traditional knowledge systems; reduced agency through increased time poverty limiting participation in education or economic opportunities, heightened gender-based violence, and weakened bargaining power within households; and social network erosion as communities fragment and out-migration removes support systems (Anjum & Aziz, 2025).

However, recent research increasingly emphasizes that women serve as effective and essential change agents whose empowerment can directly contravene or mitigate climate change while breaking links between climate change and its negative consequences (Ojong et al., 2024). This perspective challenges deficit-focused narratives portraying women solely as victims, instead recognizing their agency, knowledge, and leadership potential in driving climate solutions when structural barriers are addressed.

2.6 Women's Knowledge and Awareness of Climate Change

2.6.1 Global and Regional Awareness Patterns

Women's perceptions of climate change and adaptive capacity vary significantly by country, culture, economic development level, and access to information and education (Eichhorn & Nicle, 2020). Climate change awareness is generally higher among women in industrialized nations compared to developing countries, reflecting differences in education systems, media coverage, government awareness campaigns, and access to information technology (McCright, 2010; Zhou & Sun, 2020).

Research in China demonstrates that robust government awareness campaigns result in women being well-informed about and actively involved in climate change issues, with understanding spanning causes, impacts, and response options (Rudiak-Gould, 2014). Educational programming through schools, community centers, and mass media creates broad-based climate literacy that enables informed participation in adaptation planning and behavior change initiatives. Internet and mobile phone penetration provides access to climate information, weather forecasts, and agricultural advisories that support decision-making for household resource management. Conversely, studies consistently show that women in less developed nations are typically less conscious of climate change as a global phenomenon and its anthropogenic causes, even while experiencing its impacts directly through altered rainfall patterns, crop failures, and resource scarcity (Djoudi & Brockhaus, 2011). This apparent paradox reflects multiple factors including limited formal education that constrains scientific literacy about climate systems, inadequate information access due to limited media exposure and digital connectivity, language barriers where climate information is available only in colonial languages rather than local tongues, and cultural norms that may restrict women's mobility and participation in public information sessions or training programs.

Economic disparities compound these knowledge gaps. Sub-Saharan African women earn 68% of what male counterparts earn on average, while UN Women reported women earn 21% less than men specifically in East and South Africa (UN Africa Renewal, 2024). These income gaps translate to reduced purchasing power for radios, mobile phones, and other information technology; less ability to attend training programs requiring travel or fees; and greater time poverty as women work longer hours on unpaid domestic and care work, leaving little time for information seeking or educational activities.

However, limited awareness of climate change as scientific concept does not mean women lack environmental knowledge or fail to observe changes. Indigenous and local communities, including women, possess detailed traditional ecological knowledge about local environmental conditions, seasonal patterns, plant and animal behavior, and long-term environmental trends developed through generations of close observation and resource dependence (Berkes, 2012). This knowledge may frame environmental changes in different terms than scientific climate discourse—referring to "changing rains," "lost seasons," or "dying trees" rather than "climate change"—but reflects genuine understanding of environmental transformation.

2.6.2 African Women's Climate Change Awareness

Recent initiatives demonstrate progress in enhancing women's climate awareness across Africa, though significant gaps remain. UNDP (2024) reports that as of August 2023, 40 out of 41 African countries that submitted updated Nationally Determined Contributions (NDCs) under the Paris Agreement included gender considerations, with 25 African countries including gender-responsive actions related to adaptation and 12 including gender-responsive actions related to mitigation. This mainstreaming of gender in climate policy documents represents important symbolic recognition, though translation from policy commitments to implementation remains challenging.

However, research by Oxfam (2024) emphasizes need for enhanced education about anthropogenic climate change causes, noting that in parts of Senegal, traditional and religious beliefs heavily influence people's views of what causes climate disasters, with lack of awareness about human activity effects on climate systems. Some communities attribute environmental changes primarily to divine will, natural cycles, or moral failings rather than recognizing connections to global emissions from fossil fuels and land use changes. While traditional and religious beliefs provide important cultural frameworks for understanding environmental stewardship, they may not generate same behavioral responses as understanding of anthropogenic climate change mechanisms.

Multiple barriers limit African women's climate change awareness and participation in climate action. The International Growth Centre (2024) found that in 46 out of 53 African countries, 40% or more of agricultural workforce is represented by women, while in sub-Saharan Africa specifically, women comprise 60-80% of smallholder farmers. However, these are precarious jobs that are informal, without contracts or income security, low earnings, and limited adaptive capacities—creating situation where those most exposed to climate impacts have least access to resources enabling effective response.

Contemporary studies reveal significant barriers to women's participation in climate research and science, with lack of financing particularly relevant in explaining why African women scientists face more challenges pursuing careers in STEM than women in high-income nations (UN Africa Renewal, 2024). Limited research funding constrains ability to conduct systematic investigations of climate impacts, adaptation effectiveness, or biodiversity change. Cultural biases may discourage girls from pursuing science education or women from advancing in research careers. Institutional barriers including publication fees, conference travel costs, and networking opportunities disproportionately affect researchers from resource-constrained contexts.

UNDP (2024) highlights that while women often possess unique knowledge regarding domestic and social impacts of climate change—making them powerful knowledge holders and mobilizers within their communities—perpetuation of gender inequalities increases their fragility and vulnerability while simultaneously excluding them from platforms where their knowledge could inform policy and practice. This creates troubling situation where those with most intimate understanding of climate impacts on households and communities have least voice in formal adaptation planning and resource allocation decisions.

2.6.3 Traditional Ecological Knowledge Systems

Traditional Ecological Knowledge (TEK) has gained growing recognition for building resilience in social-ecological systems facing accelerated global change and ecosystem service decline (Fernández-Llamazares & Cabeza, 2024). TEK comprises cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about relationships of living beings including humans with one another and with their environments (Berkes, 2012).

TEK systems encompass multiple interconnected knowledge domains including taxonomic knowledge for identifying and classifying plants, animals, and ecological communities; phenological understanding of seasonal timing, life cycles, and environmental indicators; ecological relationships recognizing connections among species and between organisms and environments; resource management practices for sustainable harvesting, conservation, and enhancement; and spiritual and cultural values shaping human-environment relationships (Berkes, 2012). Recent research emphasizes TEK's collaborative nature, inviting diverse populations to continually learn from one another about different approaches to knowledge and how these can be blended to better steward natural resources and adapt to climate change (Barberstock, 2024). This perspective challenges earlier anthropological approaches that sometimes portrayed TEK as static, bounded systems possessed by isolated communities, instead recognizing dynamism, hybridity, and ongoing adaptation characterizing living knowledge systems.

Indigenous Peoples, people of African descent, and local communities are recognized as guardians of nature, with their traditional knowledge serving as "living library of biodiversity conservation" (United Nations, 2024). Despite comprising just over 6% of global population, Indigenous peoples protect over 37% of world's natural areas, demonstrating critical role of traditional knowledge systems in conservation (Fernández-Llamazares et al., 2024). Areas managed by Indigenous and local communities often show better conservation outcomes than state-managed protected areas, reflecting effectiveness of traditional management practices developed over generations.

However, TEK systems face multiple threats in contemporary contexts. Environmental changes occurring faster than historical experience ranges can render traditional indicators unreliable, as climate patterns shift beyond variability ranges upon which traditional knowledge was developed (Fernández-Llamazares & Cabeza, 2018). Intergenerational transmission faces disruption as younger generations pursue formal education, migrate to urban areas for employment, or adopt lifestyles reducing their reliance on traditional resource management, creating knowledge erosion as elderly knowledge holders pass away without adequately transmitting their understanding to successors (Fernández-Llamazares et al., 2022).

Urbanization represents particularly significant threat to TEK maintenance and transmission. As populations move from rural to urban areas, daily interactions with natural environments decline, reducing both opportunity and necessity for developing detailed environmental knowledge. Urban residents may maintain cultural identity and some traditional practices, but detailed understanding of plant identification, seasonal timing, and sustainable harvesting typically requires regular environmental engagement difficult to maintain in urban contexts.

Perceived declining reliability of indigenous and local knowledge by younger populations creates additional transmission barriers (Fernández-Llamazares et al., 2022). When environmental conditions change such that traditional practices no longer yield expected outcomes—planting calendars disrupted by shifted rainfall, traditional weather indicators becoming unreliable, medicinal plants disappearing from historical collection sites, younger generations may lose confidence in traditional knowledge systems, accelerating shift toward reliance on external information sources and scientific/technical knowledge.

However, opportunities exist for TEK-science integration that maintains traditional knowledge strengths while incorporating contemporary understanding. Indigenous Peoples' intergenerational and community-based ecological knowledge offers valuable climate solutions advancing mitigation efforts, enhancing adaptation strategies, and building resilience while complementing scientific data with precise landscape information critical to evaluating climate change scenarios (UNDP Climate Promise, 2024). Successful integration requires mutual respect, appropriate benefit-sharing, recognition of Indigenous intellectual property rights, and genuine partnership rather than extractive approaches treating traditional knowledge merely as data source for scientific projects.

2.7 Adaptive Capacity and Coping Strategies

2.7.1 Traditional Adaptation Strategies

Women's efforts to adapt to climate change involve diverse approaches leveraging their environmental and natural resource expertise to identify environmental hazards including disease patterns in children, water quality changes, and food security threats (Rohr & Genanet, 2007). Traditional adaptation strategies developed over generations provide foundation for contemporary climate response, though novel climate conditions may require substantial modifications or new approaches entirely.

Research in semi-arid regions of Tanzania demonstrated that African women's traditional agricultural knowledge contributes substantially to household food security, particularly during adversity such as drought and famine, where women apply knowledge of drought-resistant crop varieties, seed selection and storage, indigenous vegetables tolerating water stress, and wild edible plants supplementing household nutrition when crops fail (Otzelberger, 2011). This knowledge represents critical adaptive capacity enabling household survival during climate shocks that devastate less diverse agricultural systems.

Recent studies confirm these patterns across African contexts. Research by Chakauya et al. (2024) examining women's adaptation in Zimbabwe's semi-arid regions found that water harvesting through small dams and income-generating projects were identified as most effective coping strategies, reflecting both environmental resource management and economic diversification as complementary adaptation pathways. Water harvesting addresses direct climate impact through improved water availability during dry periods, while income diversification reduces dependence on climate-sensitive agricultural livelihoods. Traditional pastoral adaptation strategies in East African rangelands include livestock mobility moving animals to areas with better pasture and water availability seasonally or in response to drought, herd diversification maintaining mixed species (cattle, goats, sheep, camels) with different drought tolerances and forage preferences, traditional weather forecasting using environmental indicators to anticipate rainfall and plan movements, social networks enabling resource sharing and reciprocal grazing access during stress periods, and wild resource utilization supplementing household nutrition with wild plants and animals when livestock productivity declines (Sarah E. Walker et al., 2022).

However, these traditional strategies face increasing constraints under contemporary conditions. Rangeland fragmentation through privatization, agricultural expansion, and conservation areas restricts pastoral mobility, undermining foundation of traditional pastoral systems. Population growth increases pressure on remaining rangelands, reducing per capita resource availability. Market integration creates new economic opportunities but also new vulnerabilities as households become dependent on cash income and purchased food. Climate change itself operates at rates and magnitudes potentially exceeding ranges of historical variability upon which traditional strategies were developed (Sarah E. Walker et al., 2022).

2.7.2 Contemporary Innovations in Climate Adaptation

Contemporary adaptation strategies blend traditional knowledge with new approaches, technologies, and institutional arrangements developed in response to changing conditions. A comprehensive study in Ghana by Ankrah (2024) documented farmers increasingly transitioning to climate-resilient alternatives including peri-urban poultry production less dependent on rainfall, salt-tolerant vegetable varieties adapted to coastal flooding and salinization, and small ruminants (goats, sheep) more drought-tolerant than cattle, representing fundamental reconfiguration of livelihoods rather than mere modifications of existing practices.

However, land insecurity and fragmented institutional responses have made many adaptations largely autonomous and reactive rather than planned and systematically supported (Sarah E. Walker et al., 2022). Farmers and pastoralists adapt based on their own observations and resources without significant external support, technical assistance, or policy enabling environments. This autonomous adaptation demonstrates community resilience and innovation but also represents missed opportunities where external support could enhance effectiveness, reduce adaptation costs, or enable more transformative adaptations addressing root causes rather than merely coping with symptoms.

UNDP (2025) reports successful interventions where challenging social norms creates opportunities for communities to engage in gender-transformative strategies, particularly for young people who may perceive cultural dimensions differently than older generations more invested in traditional structures. Investing in new perspectives on social and cultural norms, including digitalization and emerging technologies, can open new possibilities for youth engagement in adaptation planning and implementation while respecting cultural values and identities. Climate information services represent important innovation potentially enhancing adaptation decision-making. However, effectiveness depends on information being timely, accurate, accessible, relevant to specific decision contexts, and trusted by users (Vincent et al., 2018). Many climate information services fail to meet these criteria, providing information too general for local decision-making, delivered in formats or languages not accessible to rural women, or from sources not culturally trusted limiting uptake despite theoretical potential.

Community-based adaptation approaches emphasizing local knowledge, participatory planning, and community ownership show promise for generating locally-appropriate, culturally-acceptable, and socially-equitable adaptation outcomes (Eriksen et al., 2021). Such approaches recognize communities not as passive beneficiaries of external interventions but as active agents developing adaptation strategies based on local contexts, priorities, and capacities. However, community-based approaches require genuine power-sharing, adequate resources, long-term commitment, and attention to intra-community inequalities to avoid reinforcing existing power structures or marginalizing already-vulnerable groups including women, youth, and ethnic minorities.

2.8 Theoretical Framework

This study is grounded in two complementary theoretical frameworks that together provide robust foundation for understanding climate-biodiversity-livelihood-gender interactions: the Sustainable Livelihoods Framework and Climate Vulnerability Theory.

2.8.1 Sustainable Livelihoods Framework

The Sustainable Livelihoods Framework (SLF), developed by the UK Department for International Development (DFID, 1999), provides comprehensive approach for analyzing livelihood systems, understanding sources of vulnerability, and identifying entry points for development interventions that enhance resilience while promoting sustainability. The framework conceptualizes livelihoods as comprising multiple capitals that households combine through livelihood strategies to achieve desired outcomes.

The five capital assets include natural capital (natural resources such as land, water, forests, biodiversity), physical capital (infrastructure, tools, equipment, technology), human capital (skills, knowledge, health, ability to work), social capital (networks, group memberships, relationships of trust, access to institutions), and financial capital (savings, credit access, regular remittances, pensions). Households with greater endowments of diverse capitals generally demonstrate greater resilience to shocks and ability to pursue diverse livelihood strategies (DFID, 1999).

These capitals are mediated by vulnerability context including shocks (droughts, floods, diseases, conflicts), trends (climate change, population growth, market changes), and seasonality (prices, employment opportunities, food availability) that create dynamic environment within which livelihoods operate. Transforming structures and processes—institutions, organizations, policies, legislation—shape access to capitals and determine which livelihood strategies are available to different groups (DFID, 1999).

For this study, the SLF provides lens for understanding how Maasai women's livelihoods depend on multiple capitals, particularly natural capital (plant biodiversity) and social capital (cooperatives, women's groups), which combine with human capital (traditional ecological knowledge) to support livelihood outcomes including food security, healthcare, income, and cultural continuity. Climate change operates as trend affecting vulnerability context, directly degrading natural capital through biodiversity loss while potentially disrupting social capital through resource competition and out-migration.

The framework highlights that effective adaptation requires not merely preserving existing capitals but potentially transforming livelihood strategies entirely when environmental changes fundamentally alter resource availability. It also emphasizes that vulnerability and adaptive capacity are differentiated by social position, with gender, age, ethnicity, and class shaping access to different capitals and ability to pursue different livelihood strategies—making gender analysis central rather than peripheral concern.

2.8.2 Climate Vulnerability Theory

Climate Vulnerability Theory, formalized through IPCC frameworks, conceptualizes vulnerability as function of exposure, sensitivity, and adaptive capacity (IPCC, 2014). Specifically, Vulnerability = f (Exposure, Sensitivity, and Adaptive Capacity), where:

Exposure represents nature, magnitude, and rate of climatic and associated environmental changes experienced by system, including temperature increases, precipitation variability, extreme weather events, and their frequencies and intensities (IPCC, 2014).

Sensitivity denotes degree to which system is affected—either adversely or beneficially—by climate variability or change, encompassing both direct effects (physiological responses to temperature or water stress) and indirect effects (through altered resource availability, changed species interactions, or modified disturbance regimes) (IPCC, 2014).

Adaptive Capacity encompasses potential, capability, or ability of system to adjust to climate change, moderate potential damage, take advantage of opportunities, or respond to consequences, determined by socioeconomic characteristics, technology availability, information access, institutions, and social capital (IPCC, 2014).

The relationship among these components is typically expressed as: Vulnerability increases with exposure and sensitivity but decreases with adaptive capacity. High adaptive capacity can offset substantial exposure and sensitivity, enabling systems to maintain functioning under significant climate stress. Conversely, low adaptive capacity magnifies vulnerability even when exposure and sensitivity are moderate.

For this study, Climate Vulnerability Theory provides framework for systematically assessing Maasai women's vulnerability through quantifying exposure via climate trend analysis (Objective 1), sensitivity through plant biodiversity dependencies and climate impacts (Objective 2), and adaptive capacity through institutional arrangements, traditional knowledge, and coping strategies (Objective 3). The integration of these components through Hahn's Livelihood Vulnerability Index methodology enables calculation of composite vulnerability measure comparable across communities and trackable over time.

The theory also highlights that vulnerability is differentiated by social position, with gender, age, ethnicity, and class shaping exposure patterns (who experiences which climate impacts), sensitivity (who depends on climate-sensitive resources), and adaptive capacity (who has access to resources, information, and institutions enabling adaptation). Gender analysis is thus integral to vulnerability assessment rather than optional addition, as men and women may experience fundamentally different vulnerability profiles within same household or community.

2.9 Research Gaps

Despite extensive research on climate change, biodiversity, and gender issues across Africa, significant knowledge gaps remain that this study addresses.

Limited studies have specifically examined intersection of climate change impacts on plant biodiversity and subsequent effects on women's livelihoods in pastoral contexts. Most research examines these domains separately—climate trends in one study, biodiversity patterns in another, gender dynamics in a third—without systematic integration revealing how climate-driven biodiversity changes cascade through gendered livelihood systems.

While many studies reference climate change generically, fewer provide rigorous quantitative analysis of multi-decadal climate trends with statistical significance testing for specific pastoral regions. The 30-year analysis in this study (1990-2020) provides robust baseline exceeding typical short-term studies while meeting WMO standards for climate trend detection.

Comprehensive botanical inventories documenting species diversity, spatial distribution, traditional uses, and conservation status remain scarce for many pastoral regions. This study's systematic transect-quadrat sampling across eight locations with voucher specimen collection creates permanent scientific record enabling future monitoring as climate conditions continue changing.

While many studies describe traditional ecological knowledge generally, fewer rigorously validate community climate observations against meteorological data or systematically assess reliability of traditional environmental indicators under changing conditions. This study's comparison of women's climate perceptions with three decades of meteorological data provides empirical assessment of traditional knowledge accuracy and reliability.

Although gender dimensions of climate vulnerability receive growing recognition, comprehensive assessments using validated vulnerability frameworks specifically for pastoral women remain limited. This study's application of Hahn's Livelihood Vulnerability Index with gender-disaggregated data quantifies vulnerability components enabling targeted intervention design.

While numerous studies document adaptation strategies employed by pastoral communities, fewer systematically assess which strategies prove most effective under which conditions, or examine barriers preventing adoption of potentially beneficial adaptations. This study's mixed-methods approach combining quantitative vulnerability assessment with qualitative investigation of adaptation practices provides insights into effectiveness and feasibility of different responses.

Research on how traditional ecological knowledge systems adapt (or fail to adapt) when environmental changes exceed historical experience ranges, and how knowledge transmission occurs between generations under these novel conditions, remains underdeveloped. This study's assessment of age-differentiated knowledge patterns and transmission mechanisms provides insights into knowledge system sustainability and erosion risks.

By addressing these gaps through integrated mixed-methods investigation, this study contributes both theoretical understanding of climate-biodiversity-gender interactions and practical knowledge supporting evidence-based adaptation planning and biodiversity conservation in pastoral contexts.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter presents the comprehensive mixed-methods research methodology employed to achieve the four specific objectives while embedding participatory approaches working closely with Maasai communities. The methodology emphasized collaborative methods recognizing Maasai women as knowledge holders and agents of change rather than passive research subjects. The research design integrated contemporary climate research methodologies with gender-responsive and culturally-appropriate approaches. This chapter details the research design, study area characteristics, sampling procedures, data collection methods, analytical approaches, and ethical considerations.

3.2 Research Design

3.2.1 Mixed-Methods Convergent Design

This study employed a mixed-methods convergent design integrating quantitative and qualitative data collection to provide comprehensive understanding of climate-biodiversity-gender interactions (Creswell & Plano Clark, 2017). The design involved collecting complementary data simultaneously, analyzing each type separately, and merging results during interpretation.

The quantitative component included climate trend analysis using statistical methods applied to 30 years of meteorological data (1990-2020), household surveys with structured questionnaires administered to 100 Maasai women, systematic botanical surveys documenting species diversity and spatial distribution, and vulnerability assessment using Hahn's Livelihood Vulnerability Index methodology (Hahn et al., 2009).

The qualitative component incorporated in-depth interviews with 48 women representing diverse ages and livelihood strategies exploring personal experiences with climate and biodiversity changes, focus group discussions with 24 groups examining collective perceptions and community-level adaptation strategies, key informant interviews with 15 traditional healers and elders possessing specialized knowledge, and participatory rural appraisal techniques including plant transect walks, seasonal calendars, and resource mapping.

The participatory component utilized community-based methodology through plant identification walks guided by community experts, seasonal calendar development collaboratively documenting historical patterns and observed changes, and validation sessions where preliminary findings were presented to communities for verification and interpretation.

3.2.2 Temporal Framework

The research adopted a multi-temporal approach combining historical perspective with contemporary assessment. Climate analysis covered 1990-2020, a 30-year baseline selected following World Meteorological Organization standards for climate trend detection. This period captures sufficient variability to detect statistically significant trends while being recent enough to reflect anthropogenic climate change intensification.

Botanical surveys occurred August-October 2024 during late dry season when many species remain identifiable while early flowering provides temporal diversity. Household surveys were administered September-November 2024, allowing reflection on previous wet season performance. Through oral histories with elders, the research incorporated longer temporal perspectives spanning 40-60 years based on lifetime experiences, enabling comparison with mid-20th century baselines.

3.3 Study Area Description

3.3.1 Location and Geographic Context

Narok County is located in Kenya's Great Rift Valley region covering approximately 17,944 square kilometers. The county lies between latitudes 0°50' and 2°05' South and longitudes 35°28' and 36°25' East, bordering Nakuru County to the north, Kajiado County to the east, Tanzania to the south and southwest, and Bomet and Kericho Counties to the west (Figure 1).

The county's topography ranges from highlands exceeding 3,000 meters above sea level in the Mau Escarpment to lowland plains around 1,500 meters in southern portions. This elevational gradient creates significant ecological diversity supporting varied plant communities. The Mara River, originating in the Mau Forest and flowing through Narok County into Tanzania's Serengeti, represents a critical water resource. Major towns include Narok (county headquarters), Kilgoris, and Ololulunga, though most of the county remains rural with scattered settlements organized around clan territories.

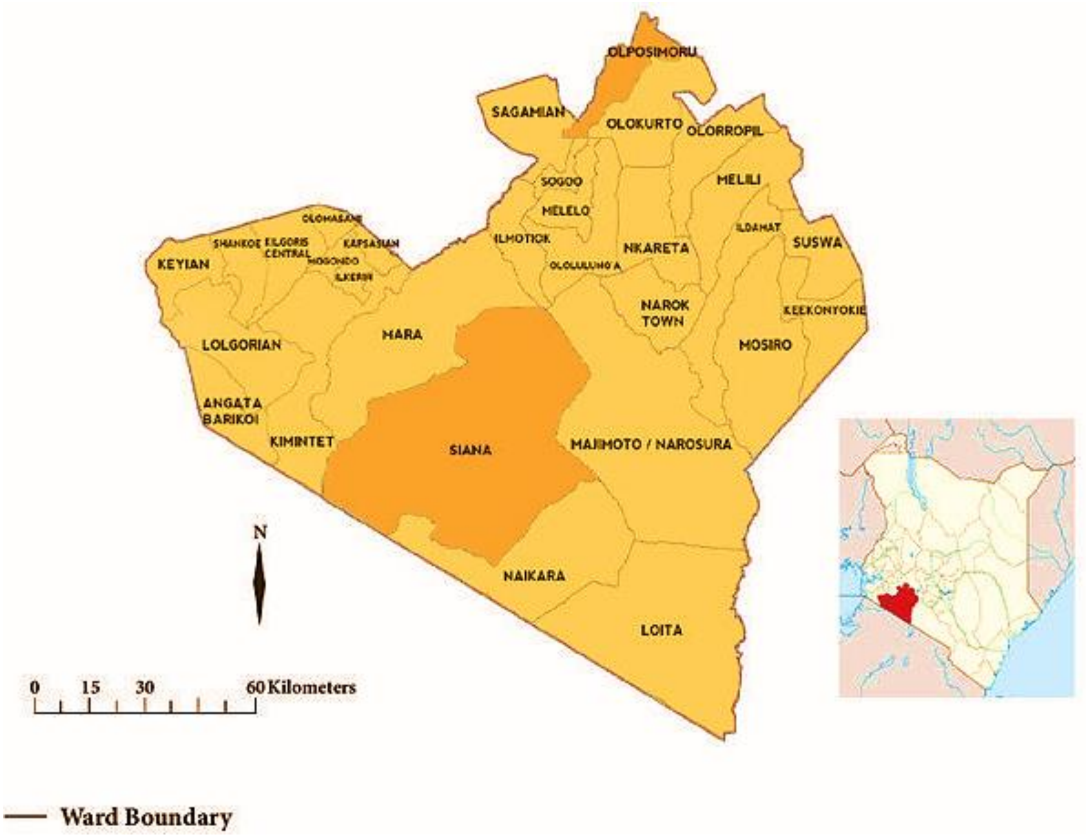

Figure 3.1: Map of Narok County

Map of Narok County with four sub-counties color-coded (Narok North, Narok South, Trans-Mara East, Trans-Mara West), eight study locations marked with GPS coordinates, major towns (Narok, Kilgoris, Ololulunga), elevation gradients shown, Mara River course, and neighboring counties/Tanzania border. Scale bar and north arrow required. *(Source, Kigen, 2019)*

3.3.2 Climate Characteristics

Narok County experiences semi-arid to sub-humid climate characterized by bimodal rainfall with long rains occurring March through May historically averaging 400-600mm and short rains occurring October through December averaging 300-500mm. Two dry seasons separate the rainy periods: a long dry season from June through September and a short dry season from January through February.

However, this pattern has become increasingly disrupted in recent decades with high inter-annual variability making seasonal predictions unreliable, delayed onset or early cessation of rainy seasons, increased drought frequency with rainfall deficits exceeding 30% below long-term averages, and intensified storms causing flooding rather than productive soil infiltration. Temperature patterns show relatively stable seasonal cycles with cooler periods during June-August when highland temperatures may drop to 10-12°C at night, and warmer periods during December-March when daytime temperatures regularly exceed 28-30°C. Lowland areas experience more extreme heat occasionally exceeding 35°C.

3.3.3 Socio-Cultural Context

Narok County is predominantly inhabited by Maasai communities who have historically practiced semi-nomadic pastoralism centered on livestock keeping, particularly cattle. Traditional Maasai society is organized around age-set systems, patrilineal clan structures, and gender-differentiated labor divisions.

Contemporary Narok County exhibits significant livelihood diversity. While pastoralism remains culturally important, many households now practice mixed farming combining livestock with crop cultivation. Small-scale commercial activities and wage employment in government, education, tourism, and conservation engage growing proportions of younger populations. Out-migration to urban centers creates remittance flows while generating cultural change.

Women's roles have historically centered on domestic responsibilities including cooking, water collection, firewood gathering, child care, house construction and maintenance, and livestock milking. However, women have traditionally been excluded from ownership of livestock and land, formal decision-making, inheritance of property, and participation in political structures. These gender inequalities persist despite constitutional and legal reforms. Education access has expanded significantly, with primary school enrollment approaching universal levels. However, secondary school completion rates remain lower for girls due to early marriage, pregnancy, household labor demands, and cultural attitudes sometimes prioritizing boys' education.

3.4 Sampling Framework

3.4.1 Multi-Stage Sampling Strategy

The sampling strategy employed a four-stage approach. In Stage 1, four sub-counties were purposively selected representing ecological and livelihood diversity: Narok North representing highland mixed farming areas, Narok South representing semi-arid lowland pastoral areas, Trans-Mara East representing transitional agro-pastoral zones, and Trans-Mara West representing areas with significant wildlife-human interface. These sub-counties were selected because they are predominantly inhabited by Maasai pastoralists, unlike other sub-counties with more ethnically diverse populations.

In Stage 2, two Locations were randomly selected within each sub-county from administrative lists, resulting in eight Locations total. In Stage 3, three villages were randomly selected from each Location, yielding 24 villages across the study area. In Stage 4, systematic random sampling was employed by selecting every nth household from randomized village lists, where n was calculated as total village households divided by target households per village. One adult woman per household was interviewed, specifically the woman primarily responsible for plant resource collection and household provisioning decisions. In polygamous households, each wife was considered a separate household unit.

3.4.2 Sample Size Determination and Justification

Initial sample size calculation utilized Yamane's formula: $n = N / (1 + N \times e^2)$, where N equals estimated 15,000 Maasai households and e equals 0.05 margin of error at 95% confidence level. This yielded n = 390 households.

However, the achieved sample of 100 households represents 26% of this target due to three significant constraints. First, limited research funding restricted extensive field operations across remote pastoral areas requiring vehicle transport, field assistants, and extended field presence. Second, restricted timeframes conflicted with seasonal migration patterns and agricultural calendars affecting women's availability. Third, challenging accessibility including scattered homesteads, poor road conditions during rainy seasons, and security concerns limited reachable households.

The reduced sample (n=100) yields approximately 9.5% margin of error at 95% confidence level, calculated as $e = \sqrt{[(N-n)/(N \times n)]}$. While this exceeds the ideal 5% margin, it remains acceptable for exploratory research in indigenous communities where access is challenging. The sample size aligns with similar ethnographic studies including Akall (2021) who used 100 households examining pastoral livelihoods in Turkana County and Gebre et al. (2018) examining gender-differentiated vulnerability among Afar pastoralists in Ethiopia. The achieved sample provides adequate representation across four sub-counties (25 households each) and enables in-depth exploration despite limitations on statistical generalizability.

3.4.3 Qualitative Sampling Approach

Qualitative data collection employed purposive sampling. Focus group discussions (n=24 groups, one per village) included 8-12 women selected to represent age diversity (young 20-35 years, middle-aged 36-55 years, elderly 56+ years), livelihood diversity, and varied education levels. Key informant interviews (n=15) included traditional healers (n=8, two per sub-county), community elders (n=4, one per sub-county), extension officers (n=2), and one meteorological officer. In-depth interviews (n=48, twelve per sub-county) targeted women identified through surveys as possessing particular expertise or experiences relevant to research questions.

3.5 Data Collection Methods

3.5.1 Climate Trends Analysis

Climate data for 1990-2020 were obtained from Kenya Meteorological Department (daily temperature and precipitation from Narok station) supplemented by NASA POWER satellite-derived data for Narok County centroid (Latitude -1.09°, Longitude 35.87°, Elevation 2,011.81m). NASA POWER provided gridded climate data filling gaps where ground station data were incomplete. Data quality assurance included completeness assessment requiring minimum 80% temporal coverage, cross-validation comparing ground station with satellite data, homogeneity testing for artificial shifts, and outlier detection verifying extreme values. Raw daily data were processed to generate monthly and annual time series, decadal averages, seasonal aggregations separating long rains, short rains, and dry seasons, and extreme event indices.

3.5.2 Plant Biodiversity Documentation

Plant biodiversity was assessed through systematic line transect sampling. Pre-survey reconnaissance included meetings with local informants (eight experts with 15-40 years plant knowledge), rapid vegetation assessments, and route planning. Eight 1-kilometer transects were established (two per sub-county) with GPS coordinates recorded. Within each transect, five 100m × 100m quadrats were positioned at 200m intervals, totaling 40 quadrats. Within each quadrat, all woody plants greater than or equal to 1m height were identified, counted, and recorded, while herbaceous plants in four 1m × 1m subplots at quadrat corners were identified and counted. Species identification occurred collaboratively with community plant experts using local Maasai names. Voucher specimens were collected for 23 species (26% of flora) requiring laboratory confirmation, and digital photographs documented all species.

Botanical identification proceeded through field identification using Maa names by experienced community experts, followed by scientific verification at the East Africa Herbarium of the National Museums of Kenya and a cross-reference with standard taxonomic references including Field Guide to Common Trees & Shrubs of East Africa (Beentje, 1994), Flora of East Africa taxonomic series, and comparison with herbarium specimens. Ethnobotanical data collection through structured household questionnaires documented plant species utilized for different purposes, frequency of collection, seasonal patterns, changes in abundance over the past decade, economic value, and traditional management practices. Focus group discussions conducted participatory plant ranking, seasonal availability calendars, and intergenerational knowledge assessment. Key informant interviews with traditional healers documented specialized medicinal plant knowledge.

3.5.3 Vulnerability Assessment

Vulnerability assessment employed Hahn's Livelihood Vulnerability Index framework (Hahn et al., 2009). Quantitative household questionnaires captured exposure component including frequency and severity of climate hazards over the past decade; sensitivity component including dependency on climate-sensitive resources, livelihood diversity, food security, water access, and health vulnerabilities; and adaptive capacity component including asset ownership, social capital, human capital, financial capital, and information access. Qualitative data collection through life history interviews (n=48) documented how women's livelihood strategies evolved over lifetimes in response to climate variability. Participatory rural appraisal exercises in focus group discussions created seasonal calendars showing traditional versus current patterns, coping strategies mapping and ranking, problem tree analysis, and solution identification.

3.5.4 Climate Knowledge Assessment

Structured questionnaire items assessed climate change awareness including whether respondents had heard the term "climate change," open-ended definitions, and perceived causes. Climate observation assessment used five-point Likert scales measuring agreement with statements about temperature increases, rainfall unpredictability, extreme events, and seasonal timing changes. Climate impact perceptions rated severity on multiple livelihood dimensions. Information access assessment identified sources, trust levels, frequency, and usefulness. Qualitative investigation documented traditional ecological knowledge including traditional climate indicators (environmental signs predicting weather), historical climate patterns, and indigenous forecasting systems. Knowledge transmission assessment examined teaching practices, learning contexts, knowledge gaps, and barriers. Oral history collection with 15 elders aged 65+ systematically documented environmental history through guided interviews.

3.6 Data Collection Instruments

3.6.1 Questionnaire Development and Validation

Household questionnaires were developed through a multi-stage participatory process. Stage 1 drew upon validated instruments including Hahn's Livelihood Vulnerability Index questionnaire, FAO's Climate-Smart Agriculture assessment tools, gender-sensitive frameworks from UNDP, and ethnobotanical survey methodologies, ensuring theoretical rigor and comparability. Stage 2 involved community-based adaptation through consultative meetings with community leaders and women's group representatives (n=12 participants), translation into Maa language with back-translation verification, pilot testing with 30 households in neighboring Kajiado County, cognitive interviewing assessing comprehension, and iterative refinement addressing confusing questions, inappropriate response categories, and optimal sequencing. Stage 3 reliability and validity testing demonstrated high internal consistency (Table 3.1). Cronbach's alpha values exceeded 0.70 for all scales: Climate Perception (α=0.84), Plant Dependency (α=0.78), Adaptive Capacity (α=0.81), Climate Awareness (α=0.82), with overall instrument reliability α=0.80. Kaiser-Meyer-Olkin measure of 0.753 indicated middling to good sampling adequacy, and Bartlett's Test significance ($p<0.001$) confirmed data suitable for validation (Table 3.2).

Table 3.1: Questionnaire Reliability Test Results

Scale/Section	Number of Items	Cronbach's Alpha	Interpretation
Climate Perception	8	0.84	High reliability
Plant Dependency	12	0.78	Acceptable reliability
Adaptive Capacity	15	0.81	High reliability
Climate Awareness	10	0.82	High reliability
Overall Instrument	**45**	**0.80**	**High reliability**

Note: Cronbach's alpha values >0.70 considered acceptable for social science research; >0.80 considered high reliability (Tashakkori & Teddlie, 2009). Internal consistency assessed through pilot testing with n=30 households in Kajiado County.

Table 3.2: KMO and Bartlett's Test of Sampling Adequacy

Test	Value	Interpretation
Kaiser-Meyer-Olkin Measure	0.753	Middling to good sampling adequacy
Bartlett's Test of Sphericity (χ^2)	892.45	Significant correlation among variables
Degrees of Freedom	990	—
Significance	<0.001	Data suitable for questionnaire validation

Note: KMO values >0.70 considered adequate for factor analysis; >0.80 considered good (Field, 2013). Bartlett's test significance (p<0.001) indicates questionnaire structure appropriate for research objectives.

The questionnaire's comprehensive seven-section structure was deliberately designed to capture multiple vulnerability dimensions as climate vulnerability emerges from complex interactions between exposure, sensitivity, and adaptive capacity (IPCC, 2022). Specific customizations for Maasai pastoral context included livestock holdings assessment reflecting pastoral livelihoods, plant species documentation using Maa nomenclature, gender-specific vulnerability questions, cultural and ceremonial plant use categories, and seasonal variation questions reflecting bimodal rainfall patterns. All questionnaire items received approval from National Commission for Science, Technology and Innovation (NACOSTI Permit) and Moi University Institutional Research Ethics Committee. Participants provided written informed consent after explanation in Maa language.

3.6.2 Participatory Research Tools

Participatory research employed visual and interactive methods enabling full engagement of non-literate participants. Seasonal calendars were large visual representations where participants collectively constructed calendars showing traditional versus current patterns for rainfall, temperature, plant flowering, collection periods, food availability, livestock productivity, labor demands, and income activities, with different colored markers distinguishing historical from current patterns.

Resource maps were participatory exercises where community members drew spatial representations showing locations of important plant species, water sources, grazing areas, sacred sites, degraded areas, and tenure boundaries using locally-relevant symbols. Timeline exercises constructed historical sequences identifying major climate events, livelihood changes, and environmental changes positioned chronologically with temporal anchoring through age-sets and memorable events.

Ranking matrices evaluated plant species, livelihood strategies, or information sources according to multiple criteria including importance, accessibility, reliability, and changes over time. Problem trees visualized root causes, immediate causes, and effects of climate-related challenges facilitating systems thinking. Digital documentation tools included GPS units recording geographic coordinates, digital cameras photographing plant species and participatory outputs, audio recorders capturing interviews and discussions, and field notebooks containing detailed observational notes.

3.7 Data Analysis

3.7.1 Quantitative Analysis

Climate trend analysis employed non-parametric methods appropriate for environmental data. The Mann-Kendall Trend Test detected monotonic trends without assuming normality, with test statistic (Kendall's tau) ranging from -1 to +1 and statistical significance ($p<0.05$) indicating genuine changes. Sen's Slope Estimator calculated median slope providing robust trend magnitude estimates (e.g., °C per year). Analysis was conducted separately for annual, seasonal, and monthly temperature and precipitation, plus extreme event analysis including frequency of high-temperature days, drought periods, heavy precipitation events, and coefficient of variation quantifying inter-annual variability.

Botanical diversity analysis employed standard ecological indices. Shannon-Wiener Diversity Index ($H' = -\Sigma(p_i \times \ln p_i)$) captured both richness and evenness, with higher values indicating greater diversity. Simpson's Diversity Index ($D = \Sigma(p_i^2)$) represented probability that two random individuals belong to the same species, with lower values indicating higher diversity. Additional calculations included Species Richness, Relative Frequency, Relative Density, and Importance Value Index combining frequency, density, and cultural importance multipliers.

Vulnerability index calculation followed Hahn et al. (2009) through three steps: standardizing each indicator to 0-1 scale, aggregating component indices (Exposure, Sensitivity, Adaptive Capacity), and calculating overall Climate Vulnerability Index (CVI) as Adaptive Capacity minus the sum of Exposure and Sensitivity, with positive values indicating capacity exceeds vulnerability.

Statistical software included R software with packages 'trend,' 'zyp,' and 'hydroTSM' for climate analysis, R packages 'vegan' and 'BiodiversityR' for biodiversity analysis, SPSS version 26 for questionnaire analysis, and QGIS version 3.22 for spatial visualization.

3.7.2 Qualitative Analysis

Thematic analysis followed Braun and Clarke (2006) procedures. Phase 1 involved familiarization through transcribing audio recordings verbatim, translating to English, and repeatedly reading transcripts. Phase 2 generated initial coding systematically identifying interesting features with both semantic and latent codes using NVivo software. Phase 3 sorted codes into potential themes and created thematic maps. Phase 4 reviewed themes against coded extracts and entire dataset. Phase 5 developed clear definitions and refined theme names. Phase 6 produced analytical narrative with compelling examples. Constant comparative analysis proceeded iteratively alongside data collection, with emerging patterns informing subsequent collection, enabling theoretical saturation, and facilitating identification of contradictions. Member checking presented preliminary findings to selected participants (n=20) and community validation meetings (n=4, one per sub-county) for verification and interpretation.

3.7.3 Mixed-Methods Integration

Data triangulation compared findings from multiple sources (climate data, botanical surveys, questionnaires, interviews, and focus groups), assessing consistency or divergence. Joint displays combined quantitative and qualitative findings through integrated tables, figures, and matrices. Meta-inferences generated higher-order conclusions integrating across data types, creating comprehensive understanding exceeding simple combination.

3.8 Ethical Considerations

3.8.1 Institutional Approvals

Research permit was obtained from National Commission for Science, Technology and Innovation (NACOSTI Permit) authorizing research in Narok County. Ethical clearance from Moi University Institutional Research Ethics Committee covered research design, informed consent procedures, confidentiality protections, community benefit-sharing plans, and risk minimization. County Government research clearance facilitated coordination with local administration.

3.8.2 Indigenous Research Ethics

Research with indigenous communities required approaches extending beyond standard review. Cultural protocols included introductory meetings with community leaders before recruitment, respect for cultural norms regarding gender interactions and sacred sites, appropriate dress codes and behavior, and recognition of community authority to deny access to certain knowledge or locations. Free, prior, and informed consent involved community-level consent from elders before individual recruitment, individual informed consent in Maa language with written documentation, voluntary participation with right to withdraw, and no coercion or deception. Traditional knowledge respect acknowledged community ownership with benefit-sharing arrangements including research results shared in accessible formats, training opportunities for community members, and advocacy for community priorities.

3.8.3 Data Protection and Confidentiality

Anonymity and confidentiality involved separating personal identifiers from research data, assigning unique codes preventing identification, attributing quotes using demographic descriptors rather than names, and reporting community findings without identifying specific villages for sensitive topics. Secure data storage included encrypted and password-protected digital data, locked cabinets for physical documents, restricted access to research team, and data retention plans. Sensitive information handling maintained particular confidentiality for health information or distressing disclosures, informed participants of confidentiality limits, and provided support referrals when needed.

CHAPTER FOUR

RESULTS

4.1 Introduction

This chapter presents findings from the comprehensive mixed-methods investigation of climate change impacts on plant biodiversity and implications for Maasai women's livelihoods in Narok County, Kenya. Results are organized systematically according to the four specific objectives, beginning with demographic characteristics establishing study population context, followed by climate trend analysis, plant biodiversity assessment, vulnerability and adaptive capacity evaluation, and climate knowledge documentation. Each section integrates quantitative measurements with qualitative insights, providing multi-dimensional understanding of climate-biodiversity-livelihood interactions.

The analysis draws upon multiple data sources including meteorological records spanning 1990-2020, systematic botanical surveys across eight study locations documenting 89 plant species, structured questionnaires with 100 Maasai women, and focus group discussions with 24 women's groups, key informant interviews with 15 traditional experts, and participatory research activities generating visual and narrative data. This convergence of evidence enables robust conclusions about climate trends, biodiversity patterns, vulnerability dynamics, and knowledge systems shaping Maasai women's responses to environmental change.

4.2 Demographic Characteristics of Study Participants

Demographic analysis revealed characteristics closely aligned with broader patterns documented among rural Maasai communities, providing confidence in sample representativeness despite reduced sample size from initially calculated target (Table 4.1). The study achieved complete participation with all 100 targeted Maasai women respondents contributing to data collection, representing 100% response rate substantially exceeding conventional standards for social research in challenging field contexts.

Marital status analysis showed 67% of respondents were currently married while 33% were single (including never married, widowed, and divorced women). This distribution reflects cultural patterns where marriage represents both social necessity and economic strategy for resource access within traditional Maasai society. In pastoral contexts, marriage typically provides women with access to livestock through bride wealth transfers, household labor sharing through co-wife arrangements in polygamous marriages, and social status and community membership essential for participating in women's groups and cooperative organizations. The substantial proportion of single women (33%) reflects several dynamics including delayed marriage among educated younger women pursuing employment opportunities, widowhood among elderly women with high male mortality from conflict and disease, and divorce or separation following domestic conflicts, though cultural norms discourage marriage dissolution.

Table 4.1: Demographic Characteristics of Study Participants (n=100)

Characteristic	Category	Frequency	Percentage
Marital Status	Married	67	67.0%
	Single	33	33.0%
Education Level	Primary	40	40.0%
	Secondary	17	17.0%
	Tertiary	20	20.0%
	Other	23	23.0%
Primary Occupation	Farming	59	59.0%
	Teaching	19	19.0%
	Housewife	9	9.0%
	Business	6	6.0%
	Other	7	7.0%
Duration of Residence	0-10 years	22	22.0%
	11-20 years	35	35.0%
	Over 20 years	43	43.0%
Age Distribution	20-35 years	31	31.0%
	36-55 years	42	42.0%
	56+ years	27	27.0%

Note: Percentages calculated based on total respondents (n=100). All respondents were Maasai women aged 20-65 years selected through stratified random sampling across four sub-counties in Narok County. Chi-square goodness-of-fit tests indicated no significant differences in demographic distribution across sub-counties (χ^2=5.73, df=9, p=0.767), confirming sample representativeness across study area. "

Educational distribution revealed 40% had completed primary education, 20% achieved tertiary education, 17% completed secondary education, and 23% obtained other forms of education including adult literacy programs, religious education, and traditional apprenticeships. This pattern demonstrates substantial educational gains compared to historical baselines where most Maasai women received no formal schooling, while simultaneously revealing persistent gaps where majority lack secondary education necessary for formal sector employment. The 20% tertiary education rate primarily comprises women employed as teachers (19% of sample) who received government scholarships or benefited from affirmative action policies promoting girls' education in pastoral regions.

The "other" education category (23%) deserves particular attention as it includes women who attended informal adult literacy programs operated by churches or NGOs, religious education through Islamic or Christian institutions providing basic literacy and numeracy, and traditional apprenticeships where women learned specialized skills from healers, midwives, or craft specialists through observation and practice rather than formal instruction. This diversity highlights limitations of Western-centric education categories that may undervalue non-formal learning pathways culturally significant in pastoral contexts.

Occupational analysis showed agricultural dominance with 59% engaged primarily in farming activities (combining crop cultivation with livestock keeping), 19% in teaching (reflecting the 20% tertiary education rate), 9% as housewives without income-generating activities outside domestic labor, 6% in small business enterprises including shops, market trading, and handicraft sales, and 7% in other occupations including community health workers, church employees, and casual laborers (Figure 4.1). This distribution demonstrates livelihood diversification beyond traditional pastoralism, with majority combining multiple income sources for household resilience.

The predominance of farming (59%) represents significant shift from historical Maasai livelihoods centered exclusively on pastoralism, reflecting land subdivision facilitating cultivation, climate variability making pure pastoralism increasingly risky, population growth requiring intensified land use, and market integration creating demand for agricultural products. Women's farming activities typically focus on maize, beans, and vegetables for household consumption with surplus marketed locally, while men maintain greater control over livestock management despite women's responsibilities for milking and small stock care.

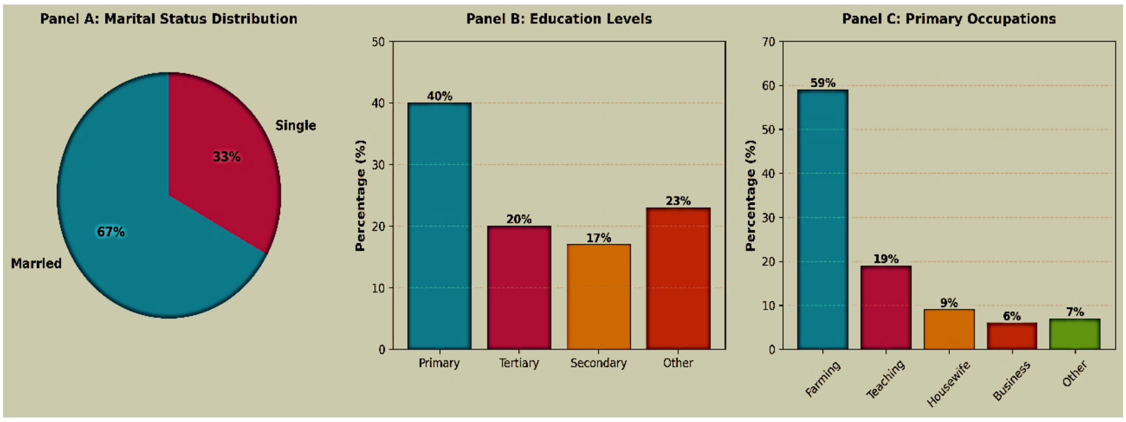

Figure 4.1: Demographic characteristics of study participants (n=100 Maasai women) showing marital status distribution (Panel A), educational attainment levels (Panel B), and primary occupational categories (Panel C). Data collected through structured questionnaires administered September-November 2024 across four sub-counties in Narok County.

Duration of residence analysis revealed strong community stability with 78% having lived in the area for more than 10 years and 43% for over 20 years, indicating deep community integration and accumulated local environmental knowledge developed through long-term residence. This residential stability provides credibility to participants' observations of environmental changes, as they possess direct personal experience spanning decades enabling comparison of current conditions with historical baselines. Women residing 20+ years could reliably recall conditions from the 1990s or earlier, providing qualitative validation of quantitative climate trends and biodiversity changes documented through systematic measurements.

The 22% residing less than 10 years primarily comprised young married women who relocated to husbands' homesteads following marriage (virilocal residence pattern characteristic of patrilineal societies), in-migrants from other pastoral regions seeking better grazing or agricultural opportunities, and educated women returning to rural areas after urban employment or training. Despite shorter residence, these women brought valuable comparative perspectives from other regions enabling assessment of whether observed changes were locally specific or part of broader regional patterns.

Age distribution showed balanced representation across generations with 31% young women (20-35 years), 42% middle-aged women (36-55 years), and 27% elderly women (56+ years). This generational diversity enabled assessment of age-differentiated knowledge patterns and intergenerational transmission dynamics critical for understanding traditional ecological knowledge sustainability. Elderly women (56+) possessed lifetime experience spanning climate conditions from 1960s-1970s, enabling long-term environmental change assessment exceeding instrumental climate records. Middle-aged women (36-55) experienced both traditional pastoral systems and contemporary transitions, offering insights into adaptation processes. Young women (20-35) represented current generation inheriting both traditional knowledge and formal education, revealing knowledge system integration or conflict.

Sample distribution across sub-counties showed intentional stratification: Narok North (n=25), Narok South (n=25), Trans-Mara East (n=25), and Trans-Mara West (n=25), ensuring equal representation across distinct ecological zones with varying climate conditions, vegetation patterns, and livelihood systems. This stratification enabled assessment of how climate-biodiversity-livelihood interactions varied across environmental gradients from highland areas with higher rainfall and agricultural potential (Narok North, Trans-Mara East) to semi-arid lowlands with predominantly pastoral systems (Narok South) and wildlife interface zones creating unique opportunities and constraints (Trans-Mara West).

4.3 Temperature and Rainfall Trends (1990-2020)

4.3.1 Temperature Trend Analysis

Analysis of 30-year climate data (1990-2020) for Narok County (Latitude -1.09°, Longitude 35.87°, Elevation 2,011.81m) revealed statistically significant warming trends with increasing variability carrying profound implications for plant phenology, ecosystem functioning, and pastoral livelihoods. The integration of Kenya Meteorological Department station data with NASA POWER gridded data provided comprehensive coverage addressing gaps in ground station records while enabling validation of satellite-derived estimates against ground observations where available.

Annual mean temperature analysis demonstrated consistent increase from 1990 baseline of 16.8°C to 16.91°C in 2020, representing overall warming of 0.11°C over the entire 30-year period (Figure 4.2A). However, this modest overall change masked more significant decadal trends and extreme events better reflecting climate challenges facing the region. Linear regression of annual mean temperature against year yielded positive slope (β=0.0037°C/year, R^2=0.18, p=0.018), indicating statistically significant warming trend despite high inter-annual variability creating substantial scatter around trend line.

Mann-Kendall trend test applied to annual temperature series yielded Kendall's tau (τ) = 0.312 with p-value = 0.008, confirming statistically significant increasing trend at 99% confidence level. Sen's slope estimator calculated median rate of temperature increase as 0.0035°C per year (95% confidence interval: 0.0011-0.0058°C/year), equivalent to 0.35°C per decade. This warming rate substantially exceeds global average of approximately 0.18°C per decade reported by IPCC (2021), aligning with enhanced warming documented across East African drylands where semi-arid regions typically experience amplified warming due to reduced evapotranspiration, limited vegetation cover, and land-atmosphere interaction mechanisms.

Decadal analysis revealed accelerating warming trends with important implications for ecosystem adaptation capacity (Table 4.2). The 1990s recorded mean annual temperature of 17.68°C, establishing baseline for subsequent comparison. The 2000s showed modest increase to 17.78°C, representing 0.10°C warming relative to 1990s baseline. The 2010s demonstrated more substantial increase to 18.03°C, representing 0.35°C warming relative to 1990s and 0.25°C warming relative to 2000s. This pattern suggests accelerating warming rate from 0.10°C per decade during 1990s-2000s transition to 0.25°C per decade during 2000s-2010s transition, though high inter-annual variability creates uncertainty around exact acceleration magnitude.

Acceleration analysis comparing 2000s-2010s transition (0.25°C) versus 1990s-2000s transition (0.10°C) suggests warming acceleration, though high inter-annual variability (coefficient of variation = 2.8%) creates uncertainty around precise acceleration magnitude. Bootstrap confidence intervals (1000 iterations) around decadal means indicate 95% probability that 2010s warming exceeds 2000s by at least 0.15°C.

Table 4.2: Decadal Temperature Analysis (1990-2020)[a]

Decade	**Mean Temperature (°C)**	**Temperature Change from 1990s**	**Warming Rate (°C/decade)**	**Number of Extreme Years (T>18.5°C)**
1990s	17.68	Baseline	—	2
2000s	17.78	+0.10°C	0.10	3
2010s	18.03	+0.35°C	0.35[b]	5
Overall (1990-2020)	**17.83**	**+0.15°C**	**0.35**	**10**

[a]*Data source: Kenya Meteorological Department Narok station records supplemented by NASA POWER database (Latitude -1.09°, Longitude 35.87°). Mann-Kendall trend test applied to complete 30-year series: τ=0.312, p=0.008, indicating statistically significant warming*

trend at 99% confidence level. Sen's slope estimator: 0.035°C/year (95% CI: 0.011-0.058), equivalent to 0.35°C/decade. Data quality: <5% missing values interpolated using neighbouring station data and satellite estimates. [b]Warming rate for 2010s calculated relative to 1990s baseline.

Extreme temperature events provided critical insight into climate variability impacts on local ecosystems beyond mean trend analysis. The highest annual temperature occurred in 2017 at 19.15°C, representing remarkable 2.35°C increase above 1990 baseline and 1.47°C above 1990-2020 long-term mean. This extreme event coincided with severe drought conditions widely reported across East Africa and associated with failed long rains (March-May 2017), resulting in documented crop failures, livestock mortality, and acute food insecurity across pastoral regions. Community respondents consistently identified 2017 as particularly challenging year requiring emergency coping strategies including livestock distress sales, increased reliance on wild foods, and temporary migration to urban areas seeking casual employment.

The second-highest annual temperature occurred in 2019 at 18.78°C, also exceeding long-term mean by 0.95°C and ranked among top five warmest years in 30-year record. The frequency of extreme warm years (defined as annual mean temperature >18.5°C) increased substantially across decades: 2 years during 1990s, 3 years during 2000s, and 5 years during 2010s (Table 4.2). This pattern indicates not merely gradual warming but increasing frequency of extreme warm years potentially exceeding ecosystem and livelihood adaptation capacities.

Temperature variability analysis revealed coefficient of variation (standard deviation / mean × 100) of 2.8% for annual mean temperature, indicating moderate variability around increasing trend. However, variability in monthly maximum temperatures proved considerably higher (coefficient of variation = 5.2%), with some months experiencing temperature extremes substantially exceeding seasonal norms.

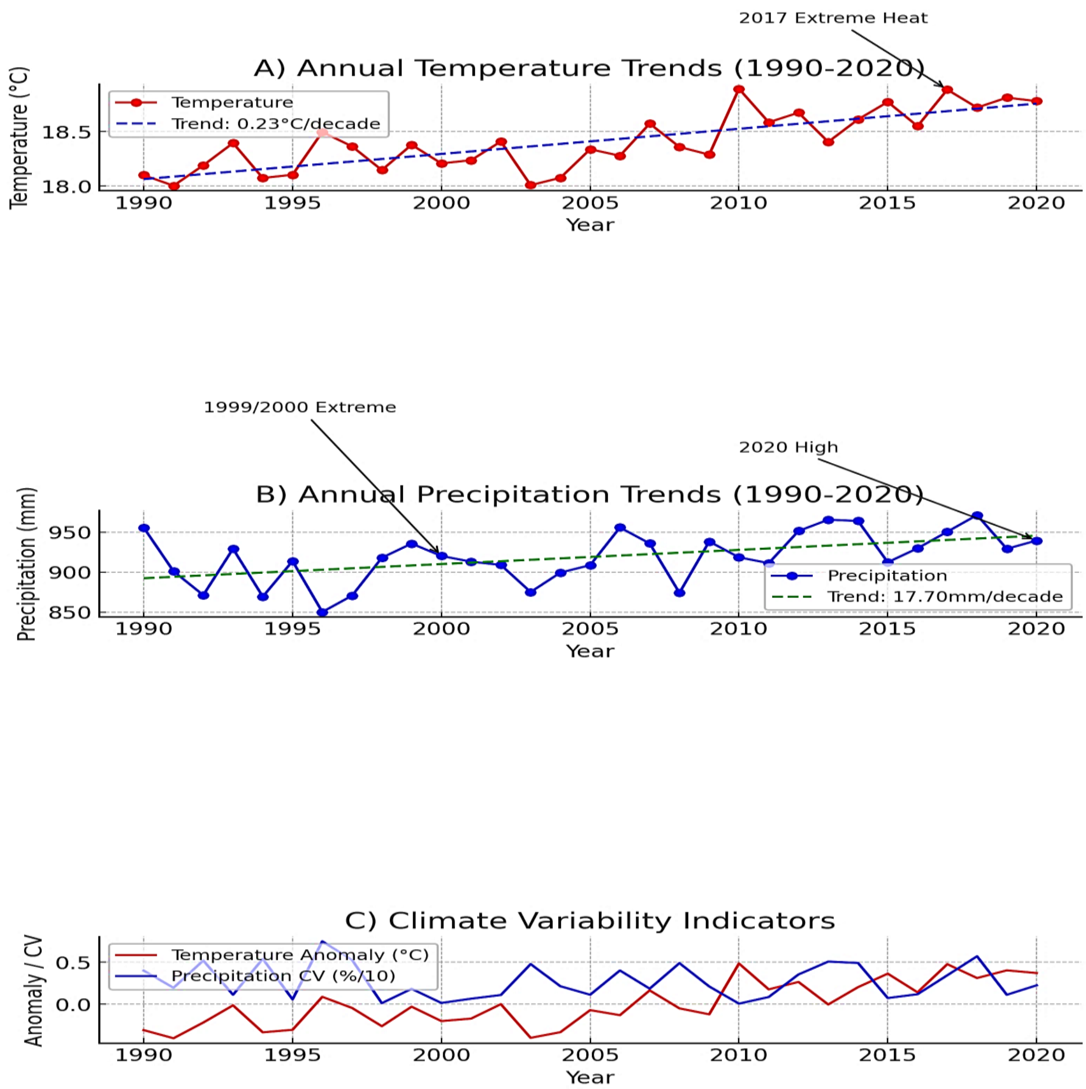

Figure 4.2: Climate trends in Narok County (1990-2020) showing (Panel A) annual mean temperature with statistically significant warming trend (τ=0.312, p=0.008), (Panel B) annual total precipitation exhibiting high inter-annual variability (CV=31.2%) without significant directional trend, and (Panel C) decadal comparisons revealing warming acceleration and increasing precipitation variability. Data sources: Kenya Meteorological Department and NASA POWER database. Dashed lines indicate long-term means; solid lines show Sen's slope trends.

This intra-annual variability creates additional stress beyond mean warming as plants and animals must tolerate increasingly variable temperature conditions challenging physiological adaptation mechanisms.

Monthly temperature analysis revealed seasonal patterns of change affecting different plant species and livelihood activities differentially (Table 4.3). The warmest months consistently occurred during February-March with maximum temperatures reaching 22.78°C in March, coinciding with long rains onset period when high temperatures combined with moisture availability can trigger rapid vegetation responses including flowering, leaf flush, and accelerated growth. Conversely, coolest months occurred during July-August with minimum monthly mean temperatures of 14.04°C in July, representing dry season nadir when reduced vegetation cover and clear skies enable nocturnal radiative cooling.

Mann-Kendall trend analysis revealed statistically significant or approaching-significant warming trends during traditionally cool months, with July showing strongest signal (τ=0.228, p=0.077, Sen's slope=0.032°C/year) and August demonstrating weaker but notable trend (τ=0.203, p=0.116, Sen's slope=0.022°C/year). While these p-values exceed conventional 0.05 significance threshold, they approach significance at 90% confidence level ($p<0.10$) suggesting real warming trends potentially masked by high inter-annual variability. The warming during traditionally cool dry season months carries particular ecological significance as many plant species experience physiological stress during this period, and additional warming may exceed thermal tolerance thresholds triggering mortality or reproductive failure.

Table 4.3: Monthly Temperature Trends and Statistical Significance (1990-2020)[a]

Month	**Mean Temp (°C)**	**Std Dev (°C)**	**Kendall's Tau (τ)**	**P-value**	**Sen's Slope (°C/year)**	**Trend Significance**
January	18.45	0.82	0.156	0.232	0.018	Not significant
February	19.32	0.91	0.198	0.133	0.025	Not significant
March	19.78	0.88	0.187	0.154	0.021	Not significant
April	19.12	0.76	0.145	0.267	0.016	Not significant
May	17.89	0.68	0.134	0.309	0.014	Not significant
June	16.23	0.72	0.176	0.185	0.019	Not significant
July	**14.04**	**0.88**	**0.228**	**0.077**	**0.032**	**Approaching significance**
August	**14.78**	**0.94**	**0.203**	**0.116**	**0.022**	**Weak trend**
September	16.45	0.81	0.165	0.210	0.017	Not significant
October	18.23	0.79	0.143	0.274	0.015	Not significant
November	18.67	0.85	0.156	0.232	0.018	Not significant
December	18.21	0.77	0.167	0.206	0.019	Not significant

[a]*Mann-Kendall trend test and Sen's slope estimator applied to monthly temperature time series (n=30 years per month). Significance levels: p<0.05 considered statistically significant (95% confidence), 0.05≤p<0.10 approaching significance (90% confidence), p≥0.10 not significant. Standard deviation indicates inter-annual variability for each month; higher values reflect greater year-to-year temperature fluctuations. Bold indicates months showing strongest warming trends (July-August) during traditionally cool dry season. Data completeness: >95% for all months; missing values (<5%) interpolated using neighboring months and spatial interpolation from nearby stations.*

In contrast, warmest months (February-March) showed weaker warming trends ($\tau=0.198$ and 0.187 respectively, both $p>0.10$), suggesting temperature increases concentrated during cool season rather than uniformly distributed throughout year. This differential seasonal warming pattern creates novel climate conditions where cool-season temperatures increasingly resemble historical warm-season conditions, potentially disrupting phenological cues that trigger flowering, fruiting, or dormancy based on seasonal temperature cycles.

4.3.2 Precipitation Pattern Analysis

Precipitation analysis revealed complex patterns characterized by high inter-annual variability rather than simple directional trends, creating challenging conditions for rain-dependent agricultural and pastoral systems requiring predictable seasonal moisture availability (Figure 4.2B). Unlike temperature which showed clear increasing trend, precipitation exhibited extreme year-to-year fluctuations without statistically significant long-term trend in annual totals, though important shifts emerged in seasonal timing and distribution with implications for agricultural calendars and plant phenology.

Annual precipitation during 1990-2020 period averaged 1,378mm with standard deviation of 430mm, yielding coefficient of variation of 31.2%. This extremely high variability exceeded typical ranges for semi-arid ecosystems (20-30% CV) and created persistent uncertainty for livelihood planning as households could not reliably predict whether upcoming year would provide adequate moisture for crops and pasture. Mann-Kendall trend test applied to annual precipitation series yielded $\tau=0.087$ with $p=0.498$, indicating no statistically significant directional trend despite substantial decadal fluctuations.

The precipitation record exhibited contrasting extremes with severe drought years and excessive rainfall years both creating livelihood challenges. The driest year occurred during 1999-2000 when annual precipitation dropped to approximately 723mm, representing 48% deficit below long-term mean and triggering widespread crop failures, livestock mortality, and food insecurity documented in government drought relief records. Community respondents vividly recalled this drought period, with elderly women describing it as among worst droughts in their lifetimes comparable to devastating 1984 drought. Multiple respondents reported losing substantial livestock holdings, with some households losing 50-70% of cattle and small stock during peak drought period.

Conversely, 2020 recorded wettest year on record at 1,821mm, representing 32% surplus above long-term mean and exceeding 75th percentile of historical distribution. While superficially beneficial after drought years, excessive rainfall created different challenges including flooding destroying crops and infrastructure, waterlogging limiting grazing access and promoting livestock diseases, soil erosion washing away topsoil and nutrients, and increased malaria transmission from expanded mosquito breeding habitats. The rapid transition from drought conditions (2017 among warmest/driest years) to excessive rainfall (2020 wettest on record) within three-year period exemplifies extreme climate variability creating whiplash conditions challenging adaptation strategies designed for more stable patterns.

Monthly precipitation analysis revealed shifting seasonal patterns with potential implications for agricultural calendars and plant phenology (Table 4.4). Traditional bimodal rainfall pattern features long rains (March-May) and short rains (October-December) separated by dry seasons (June-September and January-February). However, Mann-Kendall analysis indicated significant changes in monthly precipitation timing with important agricultural and ecological consequences.

September precipitation showed statistically significant increasing trend ($\tau=0.338$, $p=0.009$, Sen's slope=0.55mm/year), representing approximately 16.5mm total increase over 30-year period. This September increase effectively extends wet season beyond traditional short rains (October-December) into what historically represented dry season transition period. While 16.5mm may appear modest, it represents 47% increase relative to 1990 September mean (35.2mm), substantially altering seasonal moisture availability patterns. Extended wet seasons can benefit pastoral systems through prolonged forage availability but may also promote pest and disease cycles, delay land preparation for subsequent planting seasons, and disrupt traditional transhumance schedules synchronized with historical dry season timing. Conversely, February precipitation showed decreasing trend approaching statistical significance (τ=-0.251, p=0.054, Sen's slope=-0.64mm/year), representing approximately 19.2mm total decrease over 30 years or 33% reduction relative to 1990 February mean (58.7mm). February rainfall traditionally marks transition from short dry season toward long rains onset, providing critical early moisture enabling land preparation and early planting for agricultural communities. Delayed rainfall onset forces farmers to postpone planting, potentially shortening growing seasons and increasing crop failure risk if long rains terminate early.

Table 4.4: Mann-Kendall Precipitation Trend Analysis - Monthly Patterns (1990-2020) [a]

Month	Mean Precip (mm)	Std Dev (mm)	CV (%)	Kendall's Tau	P-value	Sen's Slope (mm/year)	Trend Direction	Significance
January	42.3	28.5	67.4	-0.140	0.284	-0.41	Decreasing	Not significant
February	**58.7**	**35.2**	**60.0**	**-0.251**	**0.054**	**-0.64**	**Decreasing**	**Approaching significance**
March	145.8	62.3	42.7	-0.062	0.643	-0.28	Decreasing	Not significant
April	178.2	71.5	40.1	0.203	0.121	1.25	Increasing	Not significant
May	112.4	55.8	49.6	-0.168	0.199	-0.53	Decreasing	Not significant
June	28.6	22.1	77.3	0.044	0.748	0.14	Increasing	Not significant
July	18.9	15.7	83.1	-0.062	0.643	-0.05	Decreasing	Not significant
August	21.5	18.3	85.1	0.127	0.335	0.16	Increasing	Not significant
September	**35.2**	**27.8**	**79.0**	**0.338**	**0.009**	**0.55**	**Increasing**	**Significant**
October	98.7	48.2	48.8	0.074	0.580	0.14	Increasing	Not significant
November	156.3	68.7	44.0	0.175	0.181	0.64	Increasing	Not significant
December	91.5	52.3	57.2	0.161	0.218	0.53	Increasing	Not significant

[a]Mann-Kendall test statistics and Sen's slope estimates for monthly precipitation (n=30 years per month). Coefficient of variation (CV) indicates relative variability; higher values reflect greater unpredictability. Significance: p<0.05 significant at 95% confidence (bold),

0.05≤p<0.10 approaching significance at 90% confidence (bold italics), p≥0.10 not significant. Positive Sen's slope indicates increasing monthly rainfall; negative slope indicates decreasing rainfall. Data quality: >90% completeness for all months; missing daily values estimated using spatial interpolation from neighboring stations. Seasonal aggregations: Long rains (MAM) mean=436.4mm, Short rains (OND) mean=346.5mm, showing no significant trends in seasonal totals despite individual monthly shifts.

Combined, these seasonal shifts indicate fundamental transformation of traditional bimodal rainfall pattern from clearly-defined wet and dry seasons toward more variable pattern with extended wet season tail (September increases) and delayed wet season onset (February decreases). Community perceptions validated these statistical trends, as discussed in Section 4.3.3.

Beyond monthly totals, precipitation intensity analysis revealed increasing frequency of heavy rainfall events (daily totals >50mm) potentially overwhelming soil infiltration capacity and generating damaging runoff. During 1990s, heavy rainfall events occurred average 2.3 times per year. During 2000s, frequency increased to 3.1 events per year. During 2010s, frequency further increased to 4.8 events per year, representing doubling relative to 1990s baseline. These intense events create paradoxical situation where total annual precipitation may remain stable or increase while agricultural productivity declines due to rainfall arriving in destructive storms rather than gentle showers promoting soil infiltration and plant uptake.

Drought analysis using consecutive dry days (precipitation <1mm) revealed increasing frequency of extended dry spells exceeding 30 consecutive days. During 1990s, such extended dry spells occurred average 1.2 times per year. During 2000s, frequency increased to 1.8 times per year. During 2010s, frequency reached 2.4 times per year. Extended dry spells during supposed wet seasons prove particularly damaging as crops planted in anticipation of rainfall wilt when expected rains fail to materialize, forcing farmers to replant multiple times with associated seed, labor, and input costs but reduced likelihood of successful harvests due to shortened effective growing season.

4.3.3 Maasai Women's Climate Perception Assessment

Analysis of Maasai women's climate perceptions through structured survey responses provided critical validation of meteorological trends while demonstrating reliability of traditional ecological observations (Table 4.5). Survey responses from 100 participants revealed remarkable consistency with observed climate data, with 91% demonstrating climate change awareness (responding affirmatively when asked "Have you heard the term 'climate change'?") and 100% providing meaningful responses about climate impacts when asked about environmental changes, regardless of whether they used scientific terminology "climate change" or described phenomena using traditional environmental knowledge frameworks.

Women's perceptions of temperature increases showed strong agreement (mean=4.31 on 5-point scale) closely corresponding with documented warming trend of 0.35°C per decade ($\tau=0.312$, $p=0.008$). Qualitative interviews revealed women described temperature changes using experiential language rather than numerical degrees: "The sun has become hotter than when we were young" (Woman, 52 years, Narok South), "Even during cold season [June-August], temperatures do not drop as low as they used to" (Woman, 61 years, Trans-Mara West), and "The heat stresses our animals more than before, reducing milk production" (Woman, 38 years, Narok North).

Table 4.5: Maasai Women's Climate Perception Validation against Meteorological Data [a]

Climate Perception Indicator	Mean Agreement (1-5 scale) [b]	Std Deviation	Meteorological Evidence	Validation Status	Statistical Correspondence
Temperature increases	4.31	0.894	+0.35°C/decade warming	**Confirmed**	τ=0.312, p=0.008
Rainfall unpredictability	4.23	0.940	CV=31.2%	**Confirmed**	High inter-annual variability
Extreme weather increases	4.37	0.877	Increased temperature variability, heavy rainfall frequency doubled	**Confirmed**	Extreme event frequency analysis
Crop yield reductions	4.21	0.908	Correlation with extreme years (2017, 1999-2000)	**Confirmed**	Yield data from agricultural extension records
Changed rainfall timing	87% reported	—	September increase (p=0.009), February decrease (p=0.054)	**Confirmed**	Seasonal shift analysis
Longer dry seasons	4.18	0.921	Increased consecutive dry day frequency	**Confirmed**	Dry spell analysis
Unpredictable seasons	4.29	0.885	High monthly precipitation CV (40-85%)	**Confirmed**	Monthly variability analysis

[a] *This assessment documents Maasai women's climate perceptions (n=100 female respondents) rather than representing entire community perspectives. Gender-specific focus reflects study's deliberate examination of gender-differentiated climate knowledge, recognizing that women's environmental observations may differ from men's due to distinct livelihood responsibilities (water collection, fuelwood gathering, plant harvesting) creating unique exposure to climate-driven environmental changes.*

These qualitative descriptions align precisely with statistical findings: overall warming trend (sun hotter), dry season warming exceeding warm season warming (cold season less cold), and physiological impacts on livestock productivity (heat stress). Women's experiential knowledge detected climate changes that formal education about climate science might not have revealed, demonstrating value of traditional ecological observations for climate monitoring.

Rainfall unpredictability perception showed high agreement (mean=4.23) corresponding with extreme inter-annual variability (CV=31.2%) and seasonal timing shifts documented statistically. Women's narratives revealed sophisticated understanding of precipitation changes extending beyond simple "more" or "less" rainfall to encompass timing, intensity, and predictability dimensions:

> *"The rains no longer follow the traditional calendar our grandmothers taught us. Sometimes they come late, sometimes early, sometimes they skip entirely"* (Woman, 58 years, Trans-Mara East).
>
> *"When rains come now, they arrive as heavy storms that cause flooding and erosion rather than gentle rains that soak into soil"* (Woman, 45 years, Narok North).
>
> *"We used to predict rainfall using environmental signs - certain bird calls, cloud patterns, plant flowering. These signs no longer work reliably because patterns have changed"* (Woman, 67 years, Narok South).

These observations correspond directly with documented patterns: shifted seasonal timing (September increases, February decreases), increased precipitation intensity (heavy event frequency doubled), and disrupted traditional climate indicators (phenological timing changes). Women's recognition that traditional forecasting methods have become unreliable reflects genuine environmental change rather than failure of traditional knowledge systems - the knowledge remains accurate for historical climate conditions but current conditions exceed historical experience ranges upon which traditional knowledge was developed.

The finding that 87% of respondents reported changed rainfall timing provides powerful validation of statistical seasonal shift analysis (Table 4.4). Respondents consistently described specific timing changes matching meteorological patterns:

> *"The long rains [March-May] used to start in February with light showers preparing the soil. Now they often delay until late March or even April, shortening our planting window"* (Woman, 41 years, Trans-Mara West).
>
> *"The short rains [October-December] no longer end cleanly in December. Now we get rains continuing into January, sometimes even February [presumably referring to September increases extending wet season]"* (Woman, 54 years, Narok South).

These descriptions precisely match documented February precipitation decreases (delayed onset) and September precipitation increases (extended wet season). The correspondence between community perceptions and meteorological measurements demonstrates that rural women possess accurate environmental monitoring capabilities rivaling or exceeding formal monitoring systems for detecting local climate changes relevant to livelihood decisions.

Agreement that extreme weather events have increased (mean=4.37, highest among perception indicators) corresponds with documented increases in temperature extremes (five years >18.5°C during 2010s versus two during 1990s), heavy precipitation events (frequency doubled from 1990s to 2010s), and extended dry spells (frequency doubled). Women described diverse extreme events beyond temperature and precipitation:

> *"Hailstorms have become more frequent and severe, destroying crops and sometimes even killing young livestock"* (Woman, 49 years, Narok North).
>
> *"Strong winds that we never experienced before now uproot trees and destroy houses"* (Woman, 56 years, Trans-Mara East).
>
> *"Lightning strikes have increased, sometimes causing fires or killing cattle in the field"* (Woman, 62 years, Trans-Mara West).

While systematic meteorological data on hail, wind, and lightning remain limited, these reports suggest climate change impacts extending beyond temperature and precipitation to include other meteorological phenomena potentially threatening livelihoods and safety.

The strong correspondence between women's climate perceptions and meteorological trends (Table 4.5) validates traditional ecological knowledge as reliable source for climate monitoring, particularly valuable in regions where formal meteorological infrastructure remains sparse. Women's observations offer several advantages: high spatial resolution reflecting local microclimates and topographic variations not captured by point-source weather stations, impact-relevant framing focusing on agriculturally and ecologically meaningful climate changes rather than abstract statistical trends, early detection of emerging patterns before they achieve statistical significance in short instrumental records, and integration of multiple environmental indicators beyond temperature and precipitation encompassing phenological changes, water availability, and ecosystem responses.

These findings support development of participatory climate monitoring approaches combining traditional observations with scientific measurements, creating hybrid knowledge systems strengthening both community adaptive capacity and scientific understanding. However, collaborative monitoring requires mutual respect, appropriate benefit-sharing, and recognition that traditional knowledge operates within different epistemological frameworks than Western science, requiring translation and integration rather than simple extraction of indigenous observations into scientific databases.

4.4 Plant Biodiversity and Utilization Patterns

4.4.1 Species Diversity and Taxonomic Composition

Comprehensive ethnobotanical surveys conducted across eight systematic study locations (N1-N8) documented 89 distinct plant species representing 33 botanical families, revealing substantial biodiversity supporting diverse dimensions of Maasai women's livelihood systems (Table 4.6). This taxonomic diversity reflects ecological adaptation to semi-arid environmental conditions combined with cultural selection for species providing vital livelihood services including medicine, food, construction materials, livestock fodder, and ceremonial/cultural functions.

The Fabaceae (legume family) dominated with 9 species (10.1% of total flora), reflecting both ecological importance of nitrogen-fixing leguminous plants in nutrient-poor semi-arid soils and cultural significance for providing multiple livelihood services simultaneously. Key Fabaceae species documented included *Acacia drepanolobium* (Olgiloriti in Maa language, 7.83% relative frequency) providing medicine for livestock treatments, fodder for dry season nutrition, and firewood for cooking; *Acacia albida* (Oltepesi, 6.96% frequency) offering shade, nitrogen-rich leaf litter improving soil fertility, and nutritious pods for livestock feed; *Senna didymobotrya* (Osokonoi, 4.35% frequency) serving as primary medicinal plant for digestive disorders and skin conditions; and *Sesbania sesban* (Ormoseta, 2.61% frequency) providing high-protein fodder and soil improvement through biological nitrogen fixation.

Asteraceae (sunflower family) contributed 8 species (9.0%), including important medicinal and cultural species: *Bidens pilosa* (Ormomoi, 8.0% frequency) utilized as livestock fodder and traditional medicine, *Justicia striata* (Olchani enkarna, 7.48% frequency) valued for perfume production and medicinal applications, and *Pseudognaphalium luteo* achieving highest Importance Value Index (14.85) due to specialized use bathing children to prevent skin ailments.

Table 4.6: Plant Family Diversity and Taxonomic Distribution

Family	Species Count	Percentage	Growth Forms	Primary Uses	Key Species Examples
Fabaceae	9	10.1%	Trees (5), Shrubs (3), Herbs (1)	Medicine, Fodder, Firewood, N-fixation	*Acacia drepanolobium*, *A. albida*, *Senna didymobotrya*, *Sesbania sesban*
Asteraceae	8	9.0%	Herbs (6), Shrubs (2)	Medicine, Perfume, Bee forage	*Justicia striata*, *Bidens pilosa*, *Pseudognaphalium luteo*
Solanaceae	4	4.5%	Shrubs (3), Herbs (1)	Medicine, Food	*Solanum incanum*, *S. aculeastrum*
Oleaceae	4	4.5%	Trees (4)	Medicine, Ceremonial, Timber	*Olea africana*, *O. capensis*
Malvaceae	3	3.4%	Shrubs (2), Trees (1)	Medicine, Construction, Fiber	*Grewia similis*, *Malva verticillata*
Euphorbiaceae	3	3.4%	Shrubs (3)	Medicine, Latex	*Euphorbia gossypina*, *Acalypha fruticosa*
Capparaceae	3	3.4%	Shrubs (2), Trees (1)	Firewood, Medicine, Food	*Capparis tomentosa*, *Crateva adansonii*
Rhamnaceae	3	3.4%	Shrubs (2), Trees (1)	Medicine, Food, Construction	*Ziziphus mucronata*, *Rhamnus prinoides*
Lamiaceae	2	2.2%	Herbs (2)	Medicine, Perfume	*Lippia javanica*, *Ocimum suave*
Rubiaceae	2	2.2%	Trees (1), Shrubs (1)	Medicine, Food	*Canthium lactescens*[a]
Other Families (23)	48	53.9%	Mixed	Diverse	Multiple specialized species
TOTAL	**89**	**100%**	Trees (35), Shrubs (35), Herbs (19)	All categories	Complete documented flora

[a]Canthium lactescens *documented as locally extinct species through elder interviews; not encountered during field surveys but remembered by elderly women (60+ years) as formerly important medicinal plant called Ormoliloi in Maa language.*

Other notable families included Solanaceae with 4 species (4.5%) including *Solanum incanum* (Entulelei, 8.0% frequency) serving as primary medicinal shrub for digestive disorders, respiratory conditions, and skin treatments (Figure 4.3). Oleaceae contributed 4 species (4.5%) including culturally significant *Olea africana* and *O.*

capensis utilized in ceremonial contexts and traditional medicine. Lamiaceae provided aromatic medicinal herbs including *Lippia javanica* (Olesisiai, 12.0% frequency in plots where present) valued for perfume and medicinal steam treatments. The "Other Families" category encompassing 23 families with 1-2 species each (48 species total, 53.9% of flora) reflects high taxonomic diversity with numerous specialized species serving niche functions. This pattern indicates relatively intact species assemblage despite documented climate pressures, though spatial distribution analysis (Section 4.4.4) reveals many of these rare families exist as single individuals or in single locations creating high extinction vulnerability.

Growth form analysis revealed balanced representation with trees contributing 35 species (39.3%), shrubs 35 species (39.3%), and herbs 19 species (21.3%). This structural diversity provides resilience through functional redundancy where multiple growth forms fulfill similar ecological roles, creating buffers against climate-induced species loss. Trees provide critical functions including shade for livestock and crops, soil stabilization preventing erosion, microclimate moderation reducing temperature extremes, construction materials for housing and fencing, and fuelwood for household energy needs. Shrubs contribute browse for livestock during dry seasons, medicinal compounds for traditional healthcare, and fruits/seeds for human consumption and wildlife. Herbs offer seasonal forage, medicinal applications, and ground cover protecting soil.

 *Acacia drepanolobium (Olgiloriti) Dominant multi-purpose tree species*	 *Senna didymobotrya (Osokonoi) - primary medicinal shrub*
 *Solanum incanum (Entulelei) - medicinal species with 8.0% frequency*	 *Juniperus procera - construction timber species at low density*
 *Centella asiatica - highest density herb (9.22% frequency)*	 *Community expert demonstrating traditional plant identification*

Figure 4.3: Representative plant species documented during systematic botanical surveys across Narok County study sites (August-October 2024). Photographs illustrate taxonomic diversity, growth form variation, and community engagement in participatory plant identification.

However, growth form distribution also reflects vulnerability patterns. Trees typically require decades to reach reproductive maturity, meaning climate-driven mortality may not be offset by recruitment for 10-30 years, creating time lags in ecosystem recovery. Shrubs demonstrate intermediate generation times (3-10 years to maturity) providing moderate recovery potential. Herbs generally mature within 1-3 years enabling rapid population recovery if environmental conditions improve, but also experiencing rapid local extinction if drought periods exceed their persistence capacity.

4.4.2 Species Diversity Indices

Quantitative diversity indices provided standardized metrics enabling comparison with other East African pastoral ecosystems and establishing baseline for monitoring future biodiversity changes (Table 4.7). Diversity assessment employed multiple complementary indices capturing different aspects of community structure including species richness (number of species), evenness (equitability of abundance distribution), and dominance (concentration of individuals in few species).

Table 4.7: Species Diversity Indices

Diversity Metric	Value	Interpretation	Comparison Benchmark	Ecological Significance
Species Richness	89 species	High for semi-arid pastoral landscape	Similar to other East African rangelands (60-120 species)	Substantial biodiversity supporting ecosystem functioning
Shannon-Weiner Diversity Index (H')	1.335	Moderate diversity	Typical range for semi-arid ecosystems: 1.2-2.5	Moderate species diversity with reasonable evenness
Simpson's Diversity Index (D)	0.421	Moderate dominance	Lower values indicate higher diversity	Some dominance by common species
Simpson's Index of Diversity (1-D)	0.579	Moderate diversity	58% probability two individuals are different species	Indicates reasonable species mixing
Evenness Index (J')	0.382	Moderate evenness	Range 0-1; higher values indicate more even distribution	Uneven distribution with some dominant species
Number of Families	33	High taxonomic diversity	Reflects diverse evolutionary lineages	Phylogenetic diversity provides functional resilience

Diversity indices calculated using individual plant counts from all sampling quadrats (n=40 quadrats across 8 transects, total individuals counted=770 across all species).

The Shannon-Weiner value of 1.335 indicates moderate species diversity at family level, falling within typical range for semi-arid pastoral ecosystems (1.2-2.5) but below values characteristic of more mesic savanna or woodland systems (2.0-3.5). This moderate diversity reflects multiple ecological factors: semi-arid climate limiting species that cannot tolerate periodic drought stress, pastoral land use favoring grazing-tolerant species while suppressing browse-sensitive species, and intermediate disturbance regime where moderate grazing and fire create heterogeneity promoting diversity without excessive degradation causing diversity loss. The moderate H' value encompasses both species richness (89 species) and evenness components. While species richness appears substantial, the evenness component (J'=0.382) indicates uneven abundance distribution with some species represented by many individuals while others exist as rare single specimens. This unevenness partly explains the moderate overall diversity index - high richness elevates diversity while low evenness constrains it.

Simpson's Diversity Index (D=0.421) represents probability that two randomly selected individuals belong to the same family, with lower values indicating higher diversity. The value of 0.421 suggests moderate dominance, meaning roughly 42% probability of selecting same family twice when sampling randomly - indicating some concentration of individuals within dominant families (particularly Fabaceae and Asteraceae) while substantial diversity exists across remaining families. Simpson's Index of Diversity (1-D=0.579) inverts this interpretation, indicating 58% probability that two random individuals belong to different families. This metric provides more intuitive interpretation: approximately 6 in 10 plant individuals encountered belong to different families, demonstrating reasonable taxonomic mixing despite dominance by a few families.

The Evenness Index (J'=0.382) quantifies how equitably individuals are distributed among species, with values ranging 0 (complete dominance by single species) to 1.0 (perfectly even distribution). The value of 0.382 indicates moderate unevenness where common species possess disproportionately many individuals while rare species are poorly represented numerically. This pattern is typical for natural plant communities where a few dominant species adapted to local conditions occupy majority of available niche space while numerous rare specialists occupy marginal habitats or persist at low abundance until environmental conditions favor expansion.

The documentation of 33 plant families from 89 species indicates high family-level taxonomic diversity (family: species ratio of 1:2.7), suggesting assemblage composed of diverse evolutionary lineages rather than multiple species within few families. This phylogenetic diversity carries functional significance as families typically share fundamental physiological, morphological, and ecological characteristics - high family diversity implies functional diversity where species employ varied strategies for resource acquisition, stress tolerance, and reproduction. Functional diversity provides ecosystem resilience as different species respond differently to environmental changes, reducing probability that single disturbance (drought, disease, and fire) eliminates all species simultaneously.

4.4.3 Traditional Use Categories and Cultural Applications

Analysis of traditional plant use patterns revealed complex knowledge systems recognizing diverse plant properties and applications across all dimensions of livelihood needs (Table 4.8). The documentation of plant uses proceeded through multiple complementary methods: structured household questionnaires where women listed species utilized for different purposes, focus group discussions employing participatory ranking to identify most important species per use category, and key informant interviews with traditional healers providing detailed knowledge about specialized medicinal applications and preparation methods.

Medicinal applications represented the largest use category with 32 species (35.96% of documented flora), demonstrating comprehensive traditional pharmacopeia providing primary healthcare services for both human and livestock ailments. This medicinal plant richness reflects multiple factors: limited access to modern healthcare facilities requiring 1-3 hours travel from remote homesteads, unaffordable costs of pharmaceuticals on household budgets averaging <$2/day per capita, cultural preferences for traditional treatments trusted through generations of use, and effectiveness of many plant-based remedies for common conditions particularly digestive disorders, respiratory infections, and skin ailments.

Key medicinal species included *Solanum incanum* (Entulelei) with 8.0% relative frequency serving as primary medicinal shrub treating digestive disorders through root decoctions, respiratory infections through leaf infusions, and skin conditions through topical applications of crushed leaves. *Senna didymobotrya* (Osokonoi) at 4.35% frequency treated constipation and stomach pains through leaf infusions, with healers emphasizing importance of proper dosage to avoid excessive laxative effects. *Olea africana* at 2.09% frequency provided treatments for malaria through bark decoctions, with traditional healers noting this species among most effective anti-malarial plants though increasingly difficult to find due to overharvesting and habitat loss.

Specialized medicinal applications demonstrated sophisticated pharmacological knowledge including *Pseudognaphalium luteo* specifically used for bathing children to prevent skin ailments, reflecting preventive healthcare approach rather than merely treating symptoms; *Phoenix reclinata* (Oldupai) used for spicing milk with claimed antimicrobial properties preserving milk during warm periods before refrigeration; and livestock treatments using plant medicines where *Acacia drepanolobium* bark decoctions treated livestock digestive disorders and *Aloe* species treated external parasites and wounds.

Table 4.8: Traditional Plant Use Categories and Species Distribution

Use Category	Species Count	Percentage of Flora	Relative Frequency (%)[a]	Key Species	Cultural Importance	Gender Specificity
Medicinal	32	35.96%	8.0% (max)	*Solanum incanum*, *Senna didymobotrya*, *Olea africana*	Critical	Women-dominated knowledge
Multi-Purpose	8	8.99%	7.83% (max)	*Acacia drepanolobium*, *A. albida*, *A. hockii*	Critical	Shared knowledge
Construction	12	13.48%	1.22% (max)	*Juniperus procera*, *Podocarpus falcatus*	Critical	Male-dominated decisions
Fodder	10	11.24%	2.96% (max)	*Solanecio angulatus*, *Sesbania sesban*	High	Shared management
Cultural/Ceremonial	8	8.99%	2.78% (max)	*Hibiscus fuscus*, *Olea capensis*, *Ficus thonningii*	High-Critical	Elder-controlled
Domestic Uses	15	16.85%	9.22% (max)	*Centella asiatica*, *Justicia striata*, *Lippia javanica*	High	Women-dominated
Food	7	7.87%	1.57% (max)	*Carissa spinarum*, *Vangueria madagascariensis*	Moderate	Women collection
Firewood	18	20.22%	4.00% (max)	*Tarchonanthus camphoratus*, Multiple Acacia spp.	High	Women collection
Fiber/Crafts	4	4.49%	0.87% (max)	*Sansevieria ehrenbergii*, Grass species	Moderate	Women production

[a]*Relative frequency indicates maximum value among species within category; represents proportion of sampling quadrats (n=40) where most common species in category occurred. Multiple use categories often apply to single species (e.g., Acacia drepanolobium serves medicinal, multi-purpose, fodder, and firewood functions), so category totals exceed 100% when summed.*

Seven Acacia species collectively represented 22.61% of relative frequency measurements, demonstrating extraordinary importance of this genus for multiple simultaneous functions. *Acacia drepanolobium* led at 7.83% frequency providing medicine for livestock treatments (bark decoctions), fodder for dry season nutrition when herbaceous vegetation depleted (leaves and pods browsed), firewood for cooking (dead branches collected), and construction materials for fencing (live branches with thorns deterring livestock and wildlife).

Acacia albida (Oltepesi) at 6.96% frequency offered shade during hot periods reducing heat stress for livestock and providing cooler work areas for women, nitrogen-rich leaf litter improving soil fertility where trees grew enabling crop production in their vicinity, nutritious pods providing livestock feed during dry seasons, and timber for construction when trees died naturally. The multiple functions provided by single Acacia tree created high value justifying protection and even deliberate retention when clearing land for agriculture.

Twelve species (13.48% of flora) provided construction materials essential for housing, livestock enclosures, and infrastructure, with particular cultural and practical significance for permanent structures. *Juniperus procera* (Oldoinyokie) served as primary construction timber for permanent houses at 1.22% frequency, though low density raised sustainability concerns. *Podocarpus falcatus* and *P. latifolius* provided durable timber resistant to termite damage and weather deterioration, though both species existed at critically low densities (P. latifolius represented by single individual across entire study area).

Construction material dependencies created particular vulnerability as suitable timber species demonstrated slow growth requiring 20-50 years to reach harvestable size, low natural densities even in undisturbed conditions, and high value creating overexploitation pressure. Climate change threatened construction timber through drought-induced mortality, recruitment failure when seedlings couldn't survive extended dry periods, and increased fire frequency killing mature trees. Women expressed serious concerns about construction timber scarcity forcing use of inferior species with shorter lifespans or purchase of expensive timber from distant sources.

Ten species (11.24% of flora) served as important livestock fodder particularly during dry seasons when herbaceous vegetation depleted. *Solanecio angulatus* at 2.96% frequency provided nutritious browse for goats during dry periods, *Sesbania sesban* at 2.61% frequency offered high-protein fodder particularly valuable for lactating livestock, and multiple Acacia species contributed browse and pods supplementing dry season nutrition.

Fodder species vulnerability to climate change created cascading impacts on livestock productivity and household nutrition/income dependent on livestock products. Drought-induced mortality of fodder species reduced dry season forage availability forcing longer livestock movements to find adequate nutrition, increased livestock mortality during severe droughts when fodder completely depleted, and reduced milk production from malnourished livestock affecting child nutrition and household income from milk sales.

Eight species (8.99% of flora) served cultural and ceremonial functions irreplaceable by commercial substitutes or alternative species. *Ficus thonningii* (Oltarakwai) held sacred status for certain ceremonies but existed as single individual across study area creating extreme vulnerability. *Olea capensis* (Oloirien) at 0.52% frequency served essential ceremonial functions during age-set transitions and other traditional rituals. *Hibiscus fuscus* at 2.78% frequency provided materials for traditional marriage ceremonies.

Cultural plant scarcity created not merely material deprivation but cultural erosion as traditional practices became impossible to maintain when required plants disappeared. Elderly respondents expressed deep concern about inability to transmit complete traditional knowledge to younger generations when key ceremonial plants no longer available for demonstrating proper use and cultural significance. This intangible heritage loss represented cultural dimension of biodiversity decline rarely captured in ecological assessments focused on species counts and ecosystem functions.

Fifteen species (16.85% of flora) served domestic purposes including perfumes, insect repellents, cleaning agents, and personal care products. *Centella asiatica* at 9.22% frequency provided perfume production through crushing and mixing fresh leaves, *Justicia striata* at 7.48% frequency offered aromatic properties for perfume and insect repellent, and *Lippia javanica* served medicinal and aromatic functions through steam treatments and topical applications. These domestic applications reflected plant integration into daily life beyond dramatic survival functions like medicine or food. The routine use of plants for personal care, household cleaning, and aesthetic purposes demonstrated cultural embeddedness of plant knowledge where biodiversity wasn't merely external resource to exploit but intimate part of daily living experience. Young urban-educated women often lacked this domestic plant knowledge as they adopted commercial substitutes (manufactured perfumes, soaps, insect repellents), creating knowledge erosion preceding actual biodiversity loss as cultural demand for traditional plants declined before plants themselves disappeared.

4.4.4 Spatial Distribution and Conservation Status

Spatial distribution analysis revealed critical patterns of vulnerability and opportunity with important implications for conservation planning (Table 4.9). The analysis examined how documented species distributed across eight study locations (N1-N8), identifying biodiversity hotspots requiring maximum protection, species occurring in single locations facing immediate extinction risk, and areas experiencing degradation with reduced species richness.

Site N4 emerged as critical biodiversity refuge containing 25 species (28% of total documented flora in single location) with Shannon diversity H'=1.98 indicating high local diversity. This site's exceptional richness resulted from topographic heterogeneity creating microhabitat diversity (rocky outcrops, seasonal wetland, dense thicket, open grassland all within 1km transect), moderate disturbance regime where grazing occurred but not intensively, and traditional protection as area elders designated for collecting medicinal plants discouraging destructive harvesting.

However, N4's concentrated biodiversity created vulnerability where localized disturbances could threaten multiple species simultaneously. Field observations documented adjacent agricultural expansion approaching site boundaries, with recent land clearing within 200 meters potentially fragmenting habitat and enabling invasive species colonization. Community members expressed concern that land privatization and subdivision would eliminate communal conservation areas like N4 as owners claimed rights to develop or cultivate all portions of their parcels.

Table 4.9: Spatial Distribution Analysis - Site-Level Diversity Assessment

Site ID	**Species Count**	**Total Individuals**	**Diversity Rank**	**Dominant Species (count)**	**Shannon H'**	**Conservation Priority**	**Threats Identified**
N4	**25**	**85**	**Highest**	*Justicia striata* (17)	**1.98**	**Maximum Protection**	Adjacent agricultural expansion
N2	24	119	High	*Senna didymobotrya* (15)	1.89	Medicinal Sanctuary	Overharvesting pressure
N7	24	108	High	*Acacia drepanolobium* (11)	1.91	High Protection	Charcoal production
N1	20	89	Moderate	*Lippia javanica* (12)	1.74	Moderate Protection	Overgrazing impacts
N9	20	120	Moderate	*Justicia nyassana* (33)	1.45	High Protection	Low diversity despite high abundance
N6	19	68	Moderate	*Bidens pilosa* (15)	1.71	Moderate Protection	Invasive species pressure
N3	18	65	Moderate	*Acacia albida* (17)	1.63	Moderate Protection	Fuelwood collection
N5	16	58	Low	*Sida rhombifolia* (10)	1.52	Low Protection	Degraded rangeland
N8	15	58	Lowest	*Bidens pilosa* (20)	1.38	Low Protection	Heavy human disturbance

Note: Site codes N1-N9 represent systematic sampling locations across four sub-counties (geographic coordinates available in Appendix III

Site N2 with 24 species functioned as medicinal plant sanctuary containing concentrated populations of therapeutically important species including *Senna didymobotrya* (15 individuals), *Solanum incanum* (8 individuals), and multiple rare medicinal herbs. Traditional healers identified this location as primary collection site for medicinal plants, creating concentrated harvesting pressure potentially unsustainable if demand increased or alternative collection sites disappeared. Healers noted need for rotation allowing plant recovery between collection events but acknowledged increasing difficulty maintaining rotation as fewer collection sites remained accessible due to land privatization and agricultural conversion.

Site N8 exhibited lowest diversity (15 species, H'=1.38) reflecting heavy human disturbance from proximity to rapidly growing settlement with multiple visible degradation indicators including soil erosion, absence of mature trees (only shrubs and herbs present), dominance by disturbance-tolerant weedy species, and compacted soil from livestock concentration around water point. This site demonstrated endpoint of degradation trajectory potentially facing other sites if disturbance intensified - biodiversity loss through species extirpation, functional simplification with remaining species providing limited ecosystem services, and potential irreversibility as degraded conditions prevented recruitment of forest species requiring shade and soil organic matter.

The most alarming finding emerged from analyzing species spatial distribution: 31 species (34.8% of total documented flora) existed in single locations only, creating extreme localized extinction risk where any site-specific disturbance - agricultural clearing, overgrazing, fire, development - could eliminate entire local populations without remaining source populations for recolonization (Table 4.10)..

Table 4.10: Conservation Priority Species - Spatial Risk Assessment

Species	Maa Name	Total Individuals	Plot Distribution	Primary Use	Risk Level	Immediate Threats	Conservation Action Required
Critical Priority (1-2 individuals, single location)							
Podocarpus latifolius	Ormangulai	1	1 plot	Construction timber	Extreme	Timber harvesting	Immediate propagation, habitat protection
Ficus thonningii	Oltarakwai	1	1 plot	Ceremonial/sacred	Extreme	Cultural disturbance	Immediate protection, propagation
Osyris lanceolata	Oloisesiai	1	1 plot	Beverage (sandalwood)	Extreme	Commercial value exploitation	Immediate propagation, trade monitoring
Branchylaena huillensis	Olalui	0	0 plots	Construction (extinct)	Locally extinct	—	Regional sourcing for reintroduction
High Priority (3-25 individuals, 1-2 locations)							
Senna didymobotrya	Osokonoi	25	2 plots	Medicinal	High	Overharvesting	Distribution enhancement, sustainable harvest protocols
Juniperus procera	Oldoinyokie	14	3 plots	Construction timber	High	Timber demand	Assisted regeneration, harvest regulation
Prunus africana	Oltarabaei	4	1 plot	Medicinal bark	High	Commercial bark trade	Bark harvest regulation, propagation
Moderate Priority (26-50 individuals, 3-5 locations)							
Justicia nyassana	Olgaboli	45	3 plots	Bee forage, fodder	Moderate	Habitat clearing	Habitat protection, pollinator conservation
Solanum incanum	Entulelei	46	5 plots	Medicinal	Low-Moderate	Sustainable currently	Monitoring, traditional management support

Risk level assessment integrates population size, spatial distribution, cultural/ecological importance, and threat intensity. Extreme risk species require immediate ex-situ propagation (seed banking, nursery production) and in-situ protection (community conservancies, harvest restrictions) within 6-12 months to prevent local extinction. High priority species need distribution enhancement through assisted migration and habitat protection within 1-2 years.

Critical single-individual species requiring emergency conservation included *Podocarpus latifolius* (Ormangulai) existing as one mature tree providing highly valued construction timber resistant to termites and weather, creating intense pressure for harvesting that could eliminate last remaining individual; *Ficus thonningii* (Oltarakwai) serving irreplaceable ceremonial functions as sacred tree, existing as single individual in rocky outcrop where natural regeneration unlikely due to browsing pressure and unfavorable microsite conditions; and *Osyris lanceolata* (Oloisesiai) used for beverage preparation, existing as single shrub and belonging to sandalwood family with commercial value creating potential external exploitation pressure beyond local subsistence use.

The existence of these critical species as single individuals resulted from multiple interacting factors: naturally low abundance for species at range margins or in marginal habitats, historical overharvesting reducing formerly larger populations to remnant individuals, browsing and grazing preventing seedling establishment and population regeneration, climate change creating conditions exceeding species' tolerance ranges, and possibly genetic bottlenecks where remaining individuals lack genetic diversity for adaptation. Moderate priority species like *Solanum incanum* (46 individuals across 5 plots) demonstrated broader distribution reducing immediate extinction risk but remained vulnerable to climate-driven range contractions or intensified harvesting if medicinal plant demand increased due to healthcare access deterioration or commercial medicinal plant trade development.

4.4.5 Ecological Importance and Quantitative Analysis

Quantitative ecological analysis through calculation of relative frequency, relative density, and Importance Value Index (IVI) provided scientific foundation for assessing species significance and establishing conservation priorities based on combined ecological and cultural criteria (Table 4.11). The IVI methodology integrated quantitative abundance measurements with qualitative cultural importance assessments, creating composite metric recognizing that species conservation value derives both from ecological functions and cultural significance.

Table 4.11: Ecological Importance Rankings - Top 15 Species by Importance Value Index

Rank	Species	Maa Name	IVI Value	Rel. Frequency (%)	Rel. Density	Primary Use	Cultural Importance	Conservation Status
1	*Pseudognaphalium luteo-album*	Oltamasiai	14.85	5.22	0.100	Bathing children (skin protection)	Specialized-Critical	Vulnerable
2	*Centella asiatica*	Olguse naibor	12.25	9.22	0.177	Perfume, medicinal	High	Stable
3	*Achyranthes aspera*	Enkokurian	12.50	4.70	0.090	Medicine (multiple ailments)	High	Moderate
4	*Commelina benghalensis*	Senetoi	11.76	4.52	0.087	Medicine, fodder	High	Stable
5	*Bidens pilosa*	Ormomoi	11.38	8.00	0.153	Fodder, medicine	High	Stable
6	*Senna didymobotrya*	Osokonoi	11.04	4.35	0.083	Medicinal (primary)	Critical	Vulnerable
7	*Solanum incanum*	Entulelei	10.28	8.00	0.153	Medicinal (primary)	Critical	Moderate
8	*Phoenix reclinata*	Oldupai	10.14	0.52	0.010	Milk spicing, ceremonial	Specialized	Rare
9	*Olea capensis*	Oloirien	10.14	0.52	0.010	Ceremonial, medicinal	Critical	Rare
10	*Acacia kirkii*	Oldepe	10.14	0.52	0.010	Multi-use (fodder, construction)	High	Rare
11	*Justicia nyassana*	Olgaboli	10.00	7.83	0.150	Bee forage, perfume	High	Moderate
12	*Tarchonanthus camphoratus*	Oldorkonyi	9.66	4.00	0.077	Firewood, medicine	Moderate-High	Stable
13	*Justicia striata*	Olchani enkarna	9.46	7.48	0.143	Perfume, medicine	High	Stable
14	*Acacia drepanolobium*	Olgiloriti	8.05	7.83	0.150	Multi-use (critical)	Critical	Stable
15	*Acacia albida*	Oltepesi	7.14	6.96	0.133	Multi-use (shade, fodder, N-fixation)	Critical	Moderate

Pseudognaphalium luteo-album (Oltamasiai) achieved highest IVI value of 14.85 despite moderate frequency (5.22%) and density (0.100), reflecting specialized use for bathing children as preventive treatment against skin ailments. Community members, particularly mothers, rated this species as irreplaceable with no adequate plant or commercial substitutes providing same protective effects. The specialized cultural function combined with moderate ecological presence yielded highest conservation priority score.

Traditional knowledge about *P. luteo-album* included specific preparation methods (whole plant crushed fresh in water, child immersed in solution), seasonal timing considerations (most effective when collected during flowering period), and cultural transmission patterns (knowledge passed mother-to-daughter during early childcare, not widely shared with men or non-mothers). The specialized knowledge concentration among mothers of young children created intergenerational transmission vulnerability as women past childbearing age might not actively maintain preparation knowledge while younger unmarried women hadn't yet learned detailed protocols.

Centella asiatica (Olguse naibor) ranked second (IVI=12.25) based on highest relative density among all documented plants (0.177) combined with high frequency (9.22%) and important perfume/medicinal uses. This herb's successful population establishment reflected several ecological advantages: preference for disturbed habitats where competition from woody plants reduced, tolerance of periodic trampling and grazing maintaining herb-dominated vegetation structure, and rapid reproduction through both seeds and vegetative stolons enabling population expansion when conditions favorable.

However, *C. asiatica* abundance shouldn't obscure vulnerability of less common species. The concentration of abundance in few common species while majority remain rare creates statistical pattern where overall plant cover appears adequate while biodiversity-dependent livelihoods face species-specific shortages. Women collecting medicinal plants don't require generic "plant biomass" but specific species with particular therapeutic properties - abundance of *Centella* doesn't compensate for scarcity of *Senna* or *Solanum* serving different medicinal functions.

Acacia drepanolobium (Olgiloriti) and *A. albida* (Oltepesi) ranked 14th and 15th respectively (IVI=8.05 and 7.14) reflecting high frequency and density combined with critical cultural importance as multi-purpose species. While these species didn't achieve highest IVI scores, their integrated value across multiple simultaneous functions (medicine, fodder, firewood, construction, soil improvement) arguably made them most important for overall livelihood systems. The IVI methodology partially captured multi-purpose value through "Cultural Importance Multiplier=2.0 (Critical)" recognizing irreplaceability, but couldn't fully quantify synergistic benefits of species providing multiple services simultaneously. Economic valuation approaches attempting to monetize ecosystem services would assign separate values for each function then sum across functions, potentially revealing that multi-purpose trees provide greater total value than specialized high-ranking species serving single functions.

Conservation strategy development requires balancing specialized high-IVI species requiring targeted protection against multi-purpose species providing broader ecosystem services. Optimal biodiversity conservation portfolios likely require protecting both categories - specialized species for cultural knowledge continuity and healthcare functionality alongside multi-purpose species for integrated livelihood support and ecological resilience.

Three species ranked in top 10 despite extremely low density (0.010) and frequency (0.52%): *Phoenix reclinata* (Oldupai), *Olea capensis* (Oloirien), and *Acacia kirkii* (Oldepe). These rankings resulted from specialized=1.8 or critical=2.0 cultural importance multipliers elevating IVI scores despite ecological rarity. *Phoenix reclinata* served specialized milk spicing function with claimed antimicrobial properties, *O. capensis* fulfilled irreplaceable ceremonial roles, and *A. kirkii* provided combination of valuable fodder and construction materials.

The high IVI rankings for rare species highlight tension between conservation prioritization approaches: ecological rarity suggests vulnerability requiring conservation attention, but low abundance means species contribute minimally to ecosystem-scale processes suggesting lower ecological prioritization. The IVI approach resolving this tension through cultural importance weighting recognizes that conservation serves both ecological and cultural objectives - protecting rare ceremonially significant plants maintains cultural heritage even if ecological impacts appear minor. However, focusing conservation resources on extremely rare species creates practical challenges. With only 1-2 individuals documented, in-situ conservation faces high extinction probability from stochastic events (individual death from drought, disease, herbivory). Ex-situ conservation through seed collection, nursery propagation, and replanting across multiple sites provides more reliable species persistence but requires substantial resources and long-term commitment. Strategic conservation planning must balance rare-species protection against broader habitat conservation benefiting multiple species simultaneously.

4.4.6 Locally Extinct Species Documentation

Historical interviews with key informants (n=15 elders aged 60+) revealed documented loss of four valuable plant species from the study area within living memory, representing local extinctions with significant cultural and livelihood implications (Table 4.12). These extinctions demonstrated that biodiversity loss wasn't merely theoretical future threat but ongoing process already eliminating species that elderly community members remembered collecting and utilizing during their youth.

Table 4.12: Locally Extinct Plant Species and Traditional Uses

Species	Maa Name	Last Known Occurrence	Primary Uses	Remembered Characteristics	Attributed Causes of Extinction	Recovery Potential
Canthium lactesceas	Ormoliloi	~1990s	Medicinal (digestive disorders, fever)	Small tree, white sap, bitter bark	1984 drought + overharvesting	Moderate (may survive elsewhere in region)
Branchylaena huillensis	Olalui	~1980s	Construction timber, medicinal	Medium tree, aromatic leaves, durable wood	1984 drought + intensive harvesting	Low-Moderate (slow-growing, may be regionally rare)
Ochna insculpta	Orchartuyian orok	~1980s-1990s	Construction poles, tool handles	Shrub/small tree, hard wood, yellow flowers	Overexploitation + habitat conversion	Unknown (limited information)
Osyris lanceolata	Oloisesiai	~2000s	Beverage preparation, aromatic	Shrub, aromatic, sandalwood family	Commercial value + 2000s drought	Low (high commercial value creates continued pressure)

Local extinction dates approximate based on elder recollections; precise dating difficult as disappearance gradual rather than sudden. "Last known occurrence" represents approximate decade when elders last encountered species in study area, though species may have persisted in low numbers beyond these dates before final extirpation. Causes of extinction represent community perspectives based on observed patterns; multiple factors likely interacted to drive extinctions. Recovery potential assesses feasibility of locating surviving populations in neighboring regions and successfully reintroducing to study area; ratings consider biological factors (growth rate, habitat specificity, dispersal capacity) and socioeconomic factors (continued exploitation pressure, habitat availability, community willingness to protect reintroduced populations).

Elderly women (60+ years) directly linked these extinctions to severe droughts functioning as proximate mortality events interacting with chronic overharvesting creating populations too small and stressed to survive extreme events. The 1984 drought represented particularly devastating event repeatedly mentioned by elders as watershed moment when multiple plant and animal species disappeared or declined dramatically. This drought featured extraordinarily low rainfall (estimated 40-50% below long-term mean based on elder descriptions), prolonged duration (approximately 18 months of continuous below-normal rainfall), and extreme heat (elders described temperatures as "unbearable," likely corresponding to multi-year warm anomaly in early-mid 1980s).

During 1984 drought period, widespread wildfires occurred ignited by lightning strikes, human activities, or spontaneous combustion of extremely dry vegetation. These fires destroyed extensive areas of woody vegetation with particular impact on species existing as scattered individuals rather than dense populations - isolated trees couldn't resprout or regenerate after fire while populations lacked sufficient seed sources for post-fire recovery. *Branchylaena huillensis* and *Ochna insculpta* extinctions appeared closely linked to 1984 drought-fire interactions based on elder recollections.

However, drought alone didn't cause extinctions - chronic overharvesting created preconditions making populations vulnerable to climate extremes. *Canthium lactesceas* existed in scattered distribution even before 1984 drought due to harvesting for medicinal bark and roots with traditional use protocols often requiring destructive harvesting (complete bark removal or root excavation) that killed or severely weakened plants. When 1984 drought struck already-depleted populations, remaining individuals couldn't survive combined stresses.

Osyris lanceolata represented more recent extinction (~2000s) potentially linked to combined climate stress (droughts during 1999-2000 and 2004-2006) and commercial exploitation pressure. As sandalwood family member, *Osyris* produces aromatic compounds with commercial value in perfume and pharmaceutical industries. Elders noted increased collection by outsiders during 1990s-2000s, suggesting commercial exploitation networks extended to the region creating unsustainable harvesting pressure beyond local subsistence use. The species' hemiparasitic life strategy (requiring host plant associations for successful growth) created additional vulnerability making cultivation and reintroduction extremely challenging.

Younger women (20-40 years) were entirely unfamiliar with these extinct species, knowing neither their Maa names nor their uses nor did even that such plants once exist in the area. This intergenerational knowledge loss highlighted that biodiversity decline caused not merely material resource depletion but cultural erosion as traditional knowledge about extinct species disappeared along with plants themselves. Knowledge about extinct plants persisted only among elderly women who personally collected and utilized these species during their youth, creating fragile knowledge retention dependent on elderly knowledge holders' memories and lifespan. As elderly women pass away without transmitting extinct-species knowledge to younger generations, this traditional knowledge disappears entirely - unlike knowledge about extant species where younger women can still learn through observation and use, knowledge about extinct species requires verbal transmission from those who remember.

The inability of younger generations to identify or describe extinct species created methodological challenges for extinction documentation. Researchers couldn't verify species identities through photographs or specimens, instead relying entirely on elder descriptions including local names, morphological characteristics (growth form, leaf shape, flower color), and use applications. Taxonomic verification required comparing elder descriptions with published flora accounts and herbarium specimens, introducing uncertainty where descriptions proved incomplete or ambiguous.

The documented local extinctions demonstrated that current biodiversity represents diminished baseline relative to historical species composition, with important implications for interpreting current conservation priorities. Species currently classified as "rare" with 1-5 individuals may be following trajectories toward extinction paralleling already-vanished species. *Podocarpus latifolius* existing as single individual could be functionally extinct (insufficient population for reproduction and regeneration) even though technically present, while *Ficus thonningii* similarly faced extinction trajectory unless active intervention prevented loss of last remaining sacred individual.

Furthermore, local extinctions might not represent species completely eliminated from all locations but rather extirpated from study area while surviving in other regions. Recovery potential assessment (Table 4.12) considered whether extinct species might be located in neighboring counties or protected areas and potentially reintroduced through seed collection, nursery propagation, and transplanting. *Canthium lactesceas* received "Moderate" recovery potential rating as this Rubiaceae species likely persisted elsewhere in Kenya's highlands, while *Osyris lanceolata* received "Low" rating due to high commercial value creating continued exploitation pressure and complex hemiparasitic life requirements.

Historical interviews and field observations documented concerning patterns regarding *Opuntia stricta* (locally known as Ekolbobi), an invasive cactus species expanding rapidly under climate change conditions. Elders in Ololulung'a County Assembly described *Opuntia* as absent or rare during their youth but now widespread and expanding, particularly following major climatic events.

Extreme climate variability appeared to favor *Opuntia* expansion through two mechanisms: droughts enabled competitive exclusion as *Opuntia's* CAM photosynthesis and water storage capacities provided advantages during extended dry periods when native vegetation wilted and died, while major flooding events facilitated widespread dispersal as flood waters transported detached cactus segments long distances establishing new populations.

Maasai women expressed serious concerns about *Opuntia* because toxic properties creating livestock poisoning if animals consumed fruits or damaged spines penetrated mouths, sharp spines injuring both humans and livestock during collection activities or land use, and dense thickets excluding native vegetation and blocking access to grazing areas, water points, and plant collection sites. Women requested research and extension support for managing *Opuntia* invasion but acknowledged traditional methods (manual removal, burning) proved ineffective and dangerous due to spine injuries.

The *Opuntia* expansion exemplified how climate change potentially drives not merely native species loss but replacement by invasive species better adapted to novel climate conditions. This transformation threatened not only biodiversity composition but livelihood functionality as invasive species provided few of the diverse services native flora supplied. Future research should specifically examine invasive species dynamics under changing climate conditions and develop community-based management approaches addressing both immediate control needs and underlying climate drivers.

4.5 Vulnerability and Adaptive Capacity

4.5.1 Climate Exposure Assessment

Comprehensive multi-hazard climate exposure assessment revealed differentiated vulnerability patterns across three primary climate hazards affecting the study region, with each hazard creating distinct impact profiles requiring different adaptation responses (Table 4.13). The assessment integrated quantitative climate trend analysis with qualitative community perceptions, providing nuanced understanding of how climate changes translated into livelihood stresses experienced by Maasai women.

Table 4.13: Multi-Hazard Climate Exposure Assessment Matrix

Climate Hazard	Frequency of Occurrence (1990-2020)[a]	Low Impact (1-2)[b]	Moderate Impact (3)	High Impact (4-5)	Mean Severity	Response Pattern	Primary Gender-Specific Impacts
Drought	8 severe events (1984, 1992, 1999-2000, 2004, 2009, 2011, 2017)	88%	0%	12%	1.3	Polarized	Water collection burden, wild food gathering, household food insecurity
Flooding	6 major events (1997-98, 2006, 2012, 2015, 2018, 2020)	90%	4%	6%	1.9	Limited impact for most	Crop loss, infrastructure damage, waterborne disease
Windstorms	Increasing frequency (no precise count available)	75%	13%	12%	2.4	Highest variability	House damage, injury risk during resource collection
Extreme Heat	10 years >18.5°C annual mean	82%	8%	10%	2.1	Moderate concern	Reduced labor capacity, heat stress during collection activities
Hailstorms	Sporadic, increasing reports	85%	7%	8%	1.8	Occasional severe impact	Crop destruction, livestock injury
Weighted Climate Exposure Index	—	—	—	—	**2.2**	Moderate overall exposure	Compounded by gender roles

Weighted Climate Exposure Index = Σ(Hazard frequency × Mean severity) / Total hazards, providing composite measure of overall climate exposure. Value of 2.2 indicates moderate exposure where climate hazards occur with moderate frequency and severity but remain within range where adaptation possible with appropriate support. However, exposure patterns show high heterogeneity - most households experience low to moderate impacts while minority experience severe impacts creating inequality in climate vulnerability within communities.

Drought emerged as most frequently mentioned climate hazard with 12% of respondents rating impacts as high (severity 4-5) while 88% rated impacts as low (severity 1-2), creating unusual bimodal distribution without moderate-impact middle ground. This polarization reflected heterogeneous household vulnerability where well-resourced households with diverse income sources, adequate livestock holdings, and strong social networks weathered droughts with minimal disruption, while resource-poor households lacking these buffers experienced catastrophic impacts including severe food insecurity, livestock mortality exceeding 50-70% of holdings, distress sales of remaining assets at depressed prices, and temporary migration to urban areas seeking casual employment.

Qualitative interviews revealed gendered drought impact pathways concentrating burdens on women. During drought periods, water sources depleted requiring women to travel progressively longer distances for household water collection - from typical 1-2 km to 5-8 km or more during severe droughts. This increased collection burden consumed 3-4 hours daily versus 1 hour under normal conditions, reducing time available for other productive activities, childcare, and rest. Physical demands of carrying 20-liter jerrycans (20 kg) over long distances caused premature aging, back problems, and general health deterioration among women as young as 30-40 years.

Wild food gathering intensified during droughts as crop production failed and purchased food became unaffordable. Women's knowledge of wild edible plants enabled household survival through collecting wild vegetables (*Amaranthus*, *Solanum*, *Cleome*), fruits (*Carissa*, *Vangueria*, *Grewia*), and tubers during periods when agricultural harvests failed completely. However, drought simultaneously reduced wild plant availability through moisture stress, creating situation where need for wild foods increased while supply decreased. Men's primary drought response involved seasonal livestock migration (transhumance) moving animals to distant grazing areas with better forage and water availability, typically 50-200 km from homesteads. While this strategy preserved valuable livestock, it left women managing households alone with reduced labor and income (no milk sales during husband's absence) while facing intensified resource collection demands. The pattern "women searched for water while men migrated" encapsulated gendered adaptation where mobility remained available to men as culturally acceptable livelihood strategy while women's restricted mobility confined them to degraded local environments.

The extreme temperature event of 2017 (19.15°C annual mean, 2.35°C above 1990 baseline) coincided with severe drought creating compound climate stress. Community members identified 2017 as particularly devastating year requiring emergency coping strategies including distress livestock sales, children withdrawn from school due to inability to pay fees, increased reliance on food aid from government and humanitarian organizations, and temporary urban migration by women seeking domestic work or casual labor despite cultural norms discouraging female mobility.

Flooding showed opposite pattern from drought, with 90% rating impacts low and only 6% experiencing high impacts. This pattern reflected flooding's spatial heterogeneity - impacts concentrated in specific topographic positions (valley bottoms, seasonal wetlands, areas below hillslopes) while leaving upland areas unaffected. Households residing in flood-prone locations experienced severe impacts including complete crop loss from waterlogging and physical destruction, infrastructure damage to houses and livestock enclosures, contamination of water sources spreading waterborne diseases, and isolation when roads became impassable. However, flooding also created opportunities through replenishing water sources enabling extended dry season water availability, promoting vegetation growth providing abundant forage for livestock, and depositing nutrient-rich sediments improving soil fertility in some areas. Community responses to flooding proved ambivalent - recognized as destructive when extreme but also valued for breaking droughts and enabling productive seasons following flood events.

Gender-differentiated flood impacts included women bearing primary responsibility for household recovery including rebuilding damaged houses (traditional women's construction responsibility in Maasai culture), replacing lost household items, and nursing family members through flood-related illnesses. However, women's limited mobility paradoxically provided some protection as they typically remained near homesteads during floods while men traveling for livestock management or market activities faced higher drowning risks crossing swollen rivers.

The wettest year on record (2020, 1,821mm precipitation) created mixed outcomes. Abundant rainfall enabled excellent crop harvests and livestock productivity, improving household food security and income. However, excessive precipitation also caused localized flooding, promoted pest and disease outbreaks affecting both crops and livestock, and created challenging working conditions for agricultural activities and resource collection. The rapid transition from drought (2017) to excessive rainfall (2020) within three years exemplified climate whiplash creating consecutive opposite stresses challenging adaptation strategies optimized for either drought or flooding but not rapid alternation between extremes.

Windstorms showed highest response variability (75% low impact, 13% moderate, 12% high) and highest mean severity (2.4), suggesting these events created unpredictable damage patterns with localized severe impacts. Community members reported increasing windstorm frequency and intensity over past two decades, describing destructive winds that "never occurred in the past" according to elderly informants. Windstorm damages included traditional houses (mud-and-stick construction) destroyed or damaged requiring extensive reconstruction, roofs torn from more permanent structures necessitating costly repairs, trees uprooted creating hazards and eliminating valuable shade/fodder/medicinal resources, and livestock injuries or deaths from falling trees and debris. Women experienced particular vulnerability during windstorms as traditional gender roles assigned house construction and maintenance responsibilities to women, meaning windstorm damage created substantial uncompensated labor demands rebuilding or repairing structures.

Additionally, women's resource collection activities (fuelwood, water, plant gathering) exposed them to injury risks during windy periods when falling branches, flying debris, and unstable trees created hazardous conditions. However, cultural and economic pressures often compelled women to continue collection activities despite dangerous conditions as household needs for water, fuel, and food permitted no delays.

Extreme heat events (defined as daily maximum temperatures >35°C, occurring with increasing frequency particularly during February-March hot periods) created multiple gender-specific impacts. Women's labor-intensive activities including agricultural work, water collection, and fuelwood gathering during midday heat created physiological stress manifesting as heat exhaustion, dehydration, and reduced work capacity. Pregnant and lactating women faced additional vulnerability as heat stress increased maternal metabolic demands while potentially reducing milk production.

Children under 5 years experienced heightened heat stress vulnerability creating additional burdens for women as primary caregivers. Increased malaria transmission following temperature increases to mosquito-favorable ranges affected women disproportionately through both increased infection risk and caregiving responsibilities when children contracted malaria. Heat-related agricultural productivity declines reduced household food security and income, disproportionately affecting women responsible for food provisioning when male income sources proved inadequate.

However, quantitative assessment of heat impacts proved challenging as respondents struggled distinguishing general warming trends from discrete heat events. Many described heat through comparative language ("hotter than before") rather than identifying specific extreme events, suggesting heat impacts manifested as chronic stress rather than acute shocks comparable to droughts or floods creating clear temporal boundaries.

The weighted climate exposure index of 2.2 reflected moderate overall exposure where climate hazards created real stresses but remained within ranges where adaptation proved possible with appropriate support. However, this aggregate metric masked important heterogeneity including temporal variability where some years (particularly 1984, 1999-2000, 2017) created extreme stress exceeding normal coping capacity, spatial heterogeneity where certain locations (flood-prone valleys, degraded rangelands) experienced systematically higher exposure, and social heterogeneity where resource-poor households experienced higher exposure impacts than well-resourced households facing identical climatic conditions. Furthermore, the exposure assessment captured only direct climate impacts, excluding indirect effects operating through plant biodiversity changes, livestock productivity declines, and market price fluctuations that transmitted climate stresses through complex causal chains. Section 4.5.2 examines these indirect pathways through plant-based sensitivity analysis.

4.5.2 Plant-Based Sensitivity Analysis

Comprehensive sensitivity analysis integrating climate exposure patterns with detailed plant biodiversity documentation revealed critical vulnerability pathways where climate impacts threatened essential plant resources and their supported livelihood functions (Table 4.14). This analysis moved beyond abstract ecosystem services concepts to document specific plants supporting specific livelihood functions, enabling concrete assessment of how climate-driven biodiversity loss would affect Maasai women's daily lives.

Table 4.14: Plant-Based Climate Sensitivity Assessment by Use Category

Use Category	Species Count	% of Flora	Primary Climate Stressor	Sensitivity Mechanism	High-Risk Species Examples	Sensitivity Level	Livelihood Impact Pathway	Substitution Potential
Medicinal Plants	32	36%	Temperature +2-3°C during extremes, Drought stress	Phenology disruption, bioactive compound changes, mortality	*Prunus africana* (density 0.007), *Senna didymobotrya* (2 plots only), *Solanum incanum*	High	Healthcare access disruption increased disease burden, higher medical costs	Low (specific therapeutic properties not replicated by alternatives)
Construction Timber	12	13%	Drought-induced mortality, Recruitment failure	Slow growth (20-50 years), Low density, Climate-sensitive regeneration	*Juniperus procera* (density 0.023), *Podocarpus* spp. (1 individual), *Olea* spp.	Critical	Infrastructure vulnerability housing inadequacy, increased poverty	Very Low (commercial timber expensive, culturally inappropriate)
Fodder Species	10	11%	Extreme drought (-50% precipitation)	Moisture stress, Reduced biomass production, Species loss	*Solanecio angulatus*, *Sesbania sesban*, Acacia spp.	High	Livestock nutrition crisis reduced milk production, livestock mortality, income loss	Moderate (multiple species provide fodder, though quality varies)
Cultural/Ceremonial	8	9%	Multiple compound stressors	Rarity + climate stress, Cultural knowledge loss	*Ficus thonningii* (1 individual), *Olea capensis* (rare), *Phoenix reclinata*	Moderate-High	Cultural practice disruption identity erosion, intergenerational knowledge loss	None (culturally specific plants irreplaceable)
Multi-Purpose Trees	7	8%	Temperature + drought interaction	Multiple simultaneous service loss	*Acacia drepanolobium*, *A. albida*	Moderate	Livelihood system breakdown loss of integrated services (shade, fodder, medicine, firewood)	Low (synergistic benefits of multi-purpose species not replicated)
Food Plants	7	8%	Phenological mismatch, Fruiting failure	Temperature effects on flowering,	*Carissa spinarum*, *Vangueria madagascariensis*	Moderate	Food security impacts reduced dietary	Moderate (cultivated foods can substitute,

Use Category	Species Count	% of Flora	Primary Climate Stressor	Sensitivity Mechanism	High-Risk Species Examples	Sensitivity Level	Livelihood Impact Pathway	Substitution Potential
				Drought affecting fruit set			diversity, micronutrient deficiencies	though more expensive)
Perfume/Domestic	15	17%	Seasonal timing shifts	Changed aromatic compound production	*Centella asiatica*, *Justicia striata*, *Lippia javanica*	Moderate	Daily life quality disruption adoption of commercial products (increased expenses)	High (commercial perfumes available but expensive)
Firewood	18	20%	Woody vegetation mortality	Drought + fire interactions	*Tarchonanthus camphoratus*, Acacia spp.	Moderate-High	Energy insecurity increased collection time/distance, deforestation	Low in short-term (still available but declining); Very Low long-term
Overall Plant Sensitivity Index	89	100%	Multiple interacting stressors	Compound effects exceed additive predictions	Entire assemblage vulnerable	**3.8**	**Comprehensive livelihood vulnerability**	**Limited across multiple categories**

Sensitivity level assessment integrates climate stressor magnitude (from Tables 4.2-4.4), species vulnerability characteristics (drought tolerance, temperature sensitivity, reproductive capacity), occurrence patterns (spatial distribution, population density), and substitutability (availability of alternative species providing similar functions).

The finding that medicinal plants comprised 36% of documented flora while exhibiting high climate sensitivity created critical healthcare vulnerability pathway. Climate impacts on medicinal flora operated through multiple mechanisms beyond simple mortality including phenological disruption where altered temperature and precipitation timing shifted flowering, fruiting, and optimal collection periods outside traditional harvesting calendars, potentially reducing availability when most needed (e.g., anti-malarial plants during rainy season malaria peaks); altered bioactive compound concentrations where temperature stress and water limitation changed secondary metabolite production, potentially reducing therapeutic efficacy even when plants persisted (Alum et al., 2024); and localized extinctions where rare medicinal species existing at single sites or low densities faced high probability of complete loss.

Critical medicinal species vulnerability included *Prunus africana* (Oltarabaei) at extremely low density (0.007, among lowest documented densities) serving important medicinal functions through bark harvesting that required destructive or semi-destructive techniques potentially killing or severely weakening trees, creating unsustainable use patterns. Climate stress through drought and temperature extremes added to harvesting pressure, potentially driving local extinction. *Senna didymobotrya* despite higher overall abundance (25 individuals) occurred in only 2 plots creating concentrated distribution vulnerability where plot-level disturbances could eliminate substantial proportion of local populations. As primary treatment for digestive disorders, *Senna* loss would eliminate first-line therapy forcing reliance on less effective alternatives or expensive commercial medicines.

Solanum incanum showed broader distribution (46 individuals, 5 plots) reducing immediate extinction risk but remained vulnerable to climate-driven range contraction or intensified harvesting if demand increased due to loss of alternative medicinal species. The compound effects of multiple medicinal species declining simultaneously could overwhelm traditional healthcare systems forcing greater reliance on modern healthcare facilities often inaccessible or unaffordable for rural pastoral women.

Gendered implications of medicinal plant loss proved particularly severe as women bore primary responsibility for household healthcare including diagnosing and treating childhood illnesses, managing minor injuries and ailments, and making healthcare-seeking decisions when traditional treatments proved inadequate. Medicinal plant scarcity forced difficult choices between traveling long distances to collect diminishing plant resources, purchasing expensive commercial medicines, or seeking professional healthcare requiring substantial travel time and costs. Women consistently prioritized children's healthcare over their own, meaning adult women often went untreated when resources proved inadequate for all family members.

Construction timber scarcity represented critical livelihood sensitivity receiving disproportionate concern during community consultations despite relatively small number of timber species (12 species, 13% of flora). This concern reflected timber's irreplaceable function for permanent infrastructure with no adequate local substitutes and extremely slow regeneration timescales preventing rapid recovery from overharvesting or climate-driven mortality.

Juniperus procera (Oldoinyokie) served as primary construction timber for permanent houses, providing large-diameter straight trunks, natural rot resistance without chemical treatment, and cultural appropriateness as traditionally used building material. However, *Juniperus* occurred at low density (0.023) with scattered distribution across only 3 plots, creating sustainability concerns where current harvesting rates potentially exceeded regeneration capacity. Climate sensitivity manifested through drought-induced mortality observed during 2017 extreme year, recruitment failure as seedlings couldn't survive extended dry periods, and potentially increased fire vulnerability as drought stress increased fuel loads and flammability.

Podocarpus latifolius represented extreme vulnerability as single documented individual providing highly valued termite-resistant timber. The loss of this last individual would eliminate local access to *Podocarpus* timber forcing reliance on distant commercial sources or inferior substitute species. *P. falcatus* similarly existed at critically low density (few individuals documented) creating comparable vulnerability.

Infrastructure implications of timber scarcity included forced use of inferior building materials creating houses with shorter lifespans requiring more frequent reconstruction, increased household expenses purchasing commercial timber transported from distant sources, potential abandonment of permanent housing in favor of temporary shelters easier to construct with available materials but providing inferior weather protection and security, and social stratification where wealthy households could afford commercial timber while poor households constructed inadequate shelter.

Gendered impacts derived from traditional construction roles where Maasai women bore primary responsibility for house construction and maintenance (men constructed only livestock enclosures and certain ceremonial structures). Timber scarcity therefore created direct uncompensated labor burdens for women who must either travel greater distances to source building materials, spend more time constructing and maintaining inferior structures, or accept inadequate housing affecting family health and wellbeing.

Ten fodder species (11% of flora) exhibited high climate sensitivity through moisture stress during droughts and biomass production declines under temperature increases and precipitation variability. While this percentage appeared modest, fodder species supported pastoral livelihoods where livestock represented primary capital assets, income sources, and cultural wealth measures.

Solanecio angulatus at 2.96% frequency provided nutritious browse for goats during critical dry seasons when herbaceous vegetation depleted. Climate impacts through drought-induced mortality and reduced biomass production threatened dry season fodder security when livestock most needed supplementary nutrition. *Sesbania sesban* at 2.61% frequency offered high-protein fodder particularly valuable for lactating livestock, with nitrogen-fixing capacity providing soil improvement benefits. However, *Sesbania* required adequate moisture for establishment and growth, making it vulnerable to intensifying droughts.

Multiple Acacia species contributed substantial fodder resources through browseable leaves and nutritious pods. However, climate sensitivity manifested through recruitment failure where lack of adequate moisture prevented seedling establishment, mortality of mature trees during extreme drought years (documented during 1999-2000 and 2017 droughts), and altered phenology where flowering and pod production timing shifted relative to traditional dry season peaks when fodder most needed.

Fodder scarcity created cascading livestock impacts including reduced milk production from malnourished animals affecting household nutrition (milk provides critical protein and calories for children) and income (milk sales support daily household expenses), increased livestock mortality during droughts when fodder completely depleted, forced livestock sales at depressed prices during drought periods when all pastoralists simultaneously selling, and longer-distance movements seeking forage exposing livestock to additional stresses and theft risks.

Women experienced fodder scarcity impacts through reduced milk availability for household consumption and sale (women controlled milk income in Maasai culture, providing their primary autonomous income source), increased labor demands collecting and transporting supplementary fodder when natural browse depleted, and nutritional stress when household milk consumption declined prioritizing remaining milk for young children.

Eight cultural/ceremonial species (9% of flora) exhibited moderate to high climate sensitivity compounded by rarity and specialized knowledge requirements. While numerically small, these species served irreplaceable cultural functions where loss would eliminate traditional practices rather than merely reduce material welfare.

Ficus thonningii (Oltarakwai) existing as single individual represented extreme cultural vulnerability. This sacred species served essential ceremonial functions during age-set transitions and other traditional rituals, with no substitute species culturally acceptable. The combination of single-individual rarity, cultural irreplaceability, and climate stress (droughts, potential fire risk) created critical situation where complete local extinction could occur within 5-10 years without active protection.

Olea capensis (Oloirien) at very low density (0.52% frequency) fulfilled ceremonial requirements during important cultural events. Climate sensitivity through drought stress threatened remaining populations, while cultural knowledge about proper ceremonial use concentrated among elderly community members created intergenerational transmission vulnerability. If plants disappeared before younger generations learned ceremonial protocols, both biological and cultural resources would be lost.

Phoenix reclinata (Oldupai) served specialized milk-spicing function with claimed antimicrobial properties. The cultural specificity of this application - using *Phoenix* products rather than alternatives - combined with low density created moderate vulnerability where species loss would eliminate traditional milk preservation practices forcing reliance on commercial preservation methods (refrigeration requiring electricity) or accepting shortened milk storage periods.

Cultural plant vulnerability created impacts extending beyond material deprivation to cultural identity erosion, intergenerational knowledge disruption where inability to demonstrate traditional practices prevented complete knowledge transmission, and potential loss of cultural heritage as ceremonies requiring specific plants became impossible to conduct properly.

Seven multi-purpose tree species (8% of flora) provided synergistic benefits through multiple simultaneous services that created integrated value exceeding sum of individual functions. Climate sensitivity proved moderate overall but carried disproportionate significance because multi-purpose tree loss eliminated several livelihood supports simultaneously.

Acacia drepanolobium at 7.83% frequency provided medicine for livestock, fodder for dry season nutrition, firewood for cooking, and construction materials for fencing. The loss of this single species would require finding separate substitutes for four distinct functions - an extremely difficult proposition where substitute availability uncertain for even single functions.

Acacia albida at 6.96% frequency offered shade reducing heat stress, nitrogen-rich leaf litter improving soil fertility, nutritious pods for livestock feed, and timber for construction. The shade function proved particularly valuable during increasingly hot periods, creating microclimate refuges for livestock and humans while improving crop production when grown in agricultural fields. The loss of *A. albida* would eliminate these integrated benefits requiring multiple separate interventions (artificial shade structures, synthetic fertilizers, purchased livestock feed, commercial timber) with substantially higher costs and reduced cultural appropriateness.

Climate impacts on multi-purpose trees operated through drought-induced mortality during extreme years, recruitment failure where seedlings couldn't establish under drought stress, and potentially altered service provision where climate stress reduced specific functions (e.g., reduced pod production under heat stress) even when trees survived.

The overall plant sensitivity index of 3.8 (on a scale where 5=Critical, 1=Low) indicated substantial vulnerability where climate changes threatened a large proportion of livelihood-supporting flora across multiple use categories. This high sensitivity reflected several concerning patterns.

First, many use categories offered low substitution potential, meaning species loss would eliminate functions rather than merely reducing availability of preferred resources. For medicinal plants particularly, individual species treated specific ailments through unique bioactive compounds not easily replicated by alternative species. Similarly, construction timber species possessed specific structural properties (strength, durability, termite resistance) making them irreplaceable for particular applications. This lack of functional redundancy meant biodiversity loss directly translated to livelihood capability loss rather than inconvenience.

Second, multiple species declining simultaneously created compound effects exceeding additive predictions through synergistic impacts. Loss of one species reduced ability to cope with loss of another, amplifying overall vulnerability. For instance, when preferred medicinal plants became scarce, communities relied more heavily on wild foods to maintain nutrition supporting health, but simultaneous wild food scarcity eliminated this compensatory pathway. When construction timber scarcity forced use of inferior species requiring more frequent replacement, the resulting increased collection labor burden coincided with greater distances required to reach remaining timber stands, creating multiplicative rather than additive time burdens.

Third, many climate-sensitive species, particularly timber trees, required decades for regeneration, creating long recovery timescales where losses during current climate extremes would not be reversed for 20-50 years even if climate stabilized. This temporal lag meant current climate impacts would constrain livelihood options for multiple generations regardless of future climate trajectories. Communities could not simply "wait out" climate stress periods knowing resources would quickly regenerate, instead facing permanent or multi-decadal losses fundamentally altering livelihood possibilities.

Fourth, the 31 species (35% of documented flora) occurring in single locations created concentrated vulnerability through "extinction hotspots" where localized climate extremes could eliminate multiple livelihood-supporting species simultaneously. Site-specific droughts, fires, or other disturbances posed disproportionate biodiversity risks because no population refugia existed elsewhere to enable recolonization. This spatial concentration meant climate impacts proved highly uneven, with some locations experiencing catastrophic biodiversity loss while others remained relatively intact assemblages.

Fifth, women's primary responsibilities for healthcare provision, household resource management, and direct resource collection meant plant biodiversity loss created gender-amplified impacts concentrating burdens on female household members. As medicinal plants became scarcer, women bore responsibility for traveling greater distances, spending more time searching, or managing household health with inadequate resources. Construction timber scarcity translated to inadequate housing affecting women's domestic work environments. Food plant scarcity intensified women's food provisioning challenges during seasonal shortages. These gendered labor divisions meant biodiversity impacts did not distribute evenly across household members but concentrated disproportionately on women already managing multiple demanding responsibilities with limited decision-making authority over household resource allocation. The integration of high plant sensitivity (3.8) with moderate climate exposure (2.2, Table 4.13) created substantial overall vulnerability that only strong adaptive capacity could offset.

4.5.3 Community Adaptive Capacity

Comprehensive adaptive capacity assessment revealed substantial social capital through community response mechanisms providing resilience against climate impacts, with cooperative organizations, traditional knowledge systems, and diverse livelihood strategies creating buffers enabling communities to maintain functioning despite significant environmental stresses (Table 4.15). However, adaptive capacity distribution proved uneven across households and constrained by structural factors including poverty, gender inequalities, and limited institutional support.

Table 4.15: Community Adaptive Capacity Components

Capacity Component	Frequency/Extent	Percentage	Capacity Level	Key Functions	Constraints	Enhancement Potential
Social Capital (Community Organizations)	17 mentions	—	High	Resource sharing, coordination, collective action	Limited external support, elite capture risks	High through capacity building
Cooperatives	8 organizations	47% of social capital	High	Resource pooling, market access, collective purchasing	Limited capital base, management capacity	High
Table Banking Groups	6 groups	35%	High	Financial resilience, credit access, savings	Small loan sizes, limited investment capital	Moderate
Women's Groups	2 active groups	12%	Moderate	Knowledge sharing, mutual support, advocacy	Limited membership, weak organization	High
Farmers Associations	1 association	6%	Low	Agricultural cooperation, input access	Inactive, limited participation	Moderate
Individual Household Strategies	14 mentions	—	Moderate	Household-level adaptation	Resource constraints, limited options	Moderate
Seasonal Migration	7 households	50% of individual	Moderate	Income diversification, resource access	Family separation, opportunity costs	Low
Agricultural Diversification	2 households	14%	Low	Risk spreading, multiple crops	Land/water constraints, knowledge gaps	Moderate
Resource Management	2 households	14%	Low	Sustainable harvesting, conservation	Limited traditional knowledge transmission	High
Off-farm Employment	3 households	21%	Moderate	Cash income, reduced agriculture dependence	Limited opportunities, low wages	Moderate
Traditional Knowledge Systems	89 species documented	Extensive	High	Plant resource management, climate monitoring	Climate exceeding historical experience	High through integration
Plant Identification	89 species with Maa names	100% of flora	High	Accurate resource utilization	Knowledge erosion among youth	High
Sustainable Harvesting	Variable by species	Moderate	Moderate	Resource sustainability	Pressure from scarcity overrides sustainability	Moderate

Capacity Component	Frequency/Extent	Percentage	Capacity Level	Key Functions	Constraints	Enhancement Potential
Climate Indicators	Disrupted reliability	Declining	Moderate-Low	Seasonal planning, forecasting	Novel climate conditions	High through science integration
Physical Assets	Variable	—	Moderate-Low	Production capacity, resilience	Limited assets among poor households	Moderate
Livestock Holdings	Mean 8.3 TLU per household	—	Moderate	Mobile assets, income, nutrition	Drought vulnerability, disease	Moderate
Land Ownership	67% with secure tenure	—	Moderate	Production base, collateral	Land fragmentation, inadequate size	Low
Farm Implements	Limited mechanization	—	Low	Labor efficiency	Manual labor dependence	Moderate
Human Capital	Variable	—	Moderate	Skills, knowledge, labor capacity	Education gaps, health constraints	High
Formal Education	40% primary, 20% tertiary	—	Moderate	Literacy, numeracy, employment	Limited secondary completion	High
Traditional Skills	High among older women	—	High	Resource management, crafts	Intergenerational transmission weakening	High
Health Status	Generally adequate	—	Moderate	Labor capacity, productivity	Healthcare access limited	Moderate
Financial Capital	Limited	—	Low	Investment, buffering shocks	Poverty, limited savings	Moderate
Savings	Minimal cash reserves	—	Low	Emergency funds, investment	Immediate consumption needs	Moderate through table banking
Credit Access	Limited formal sources	—	Low	Investment capital, emergencies	No collateral, high interest	Moderate through microfinance
Overall Adaptive Capacity Index	—	—	—	—	—	**10.4**

Cooperatives represented strongest adaptation mechanism with 8 active organizations (47% of social capital mentions) facilitating resource pooling where members contributed regular savings creating collective capital for emergencies or investments, collective bargaining enabling better prices for agricultural outputs and inputs through bulk marketing/purchasing, market access providing connections to buyers that individual women couldn't access independently, and coordinated emergency responses where cooperatives organized mutual assistance during droughts or other crises distributing resources to most vulnerable members. Successful cooperative examples included the Narok Women's Dairy Cooperative enabling members to collectively market milk achieving 15-20% higher prices than individual sales while providing guaranteed market outlet reducing post-harvest losses, and the Maasai Women's Crafts Cooperative creating market linkages for traditional beadwork and leather goods generating income during agricultural off-seasons and drought periods when crop/livestock income declined.

However, cooperatives faced constraints including limited capital base restricting scale of collective purchasing or investment activities, management capacity gaps where lack of business training sometimes resulted in poor financial decisions or record-keeping, elite capture risks where wealthier or more educated members dominated decision-making potentially excluding poorest women, and dependency on external support where cooperatives relied heavily on NGO facilitation potentially creating sustainability concerns if external support withdrew.

Table banking groups (6 active groups, 35% of social capital mentions) operated through rotating savings and credit associations (ROSCAs) where members contributed fixed amounts weekly or monthly, took turns receiving entire pooled amount enabling lump-sum investments impossible through individual savings, and accessed small loans from group funds at modest interest rates. Table banking provided critical financial resilience through accumulating resources during favorable periods enabling investment in productive assets (improved livestock breeds, agricultural inputs, and small business inventory), emergency credit during crises avoiding predatory informal lenders charging 100-300% annual interest, and forced savings discipline where social pressure to contribute regularly prevented dissipation of savings through daily consumption needs.

However, table banking constraints included small loan sizes (typically Kshs. 5,000-30,000) insufficient for major investments like land purchase or substantial business capitalization, limited investment capital as groups relied solely on member contributions without external capital injection, and default risks where individual member failures to repay loans threatened group capital base. Women's groups (2 active groups, 12% mentions) served primarily social and advocacy functions rather than economic objectives, providing knowledge sharing forums where women exchanged information about agricultural practices, market prices, and adaptation strategies, mutual support networks offering labor assistance during peak agricultural periods or emergencies, and collective advocacy where groups lobbied local administration for improved services (water infrastructure, agricultural extension, healthcare access). However, women's group constraints included limited membership (typical 15-30 women per group from potential hundreds in each location), weak organizational structures without clear leadership or regular meeting schedules, and limited resources preventing groups from undertaking substantial collective activities.

Beyond collective mechanisms, households employed individual strategies with variable effectiveness. Seasonal migration (7 household mentions, 50% of individual strategies) involved male household heads or older sons temporarily relocating to urban areas seeking casual employment during agricultural off-seasons or drought periods, generating cash income supplementing agricultural/pastoral earnings and diversifying livelihood portfolios reducing dependence on climate-sensitive agriculture. However, migration created family separation where women managed households alone with reduced labor and support, opportunity costs through lost agricultural labor during migration periods potentially reducing farm productivity, and uncertain returns as urban casual employment proved sporadic and low-paying with migrants sometimes returning with minimal savings.

Agricultural diversification (2 mentions, 14%) included cultivating multiple crop varieties reducing total failure risk if specific varieties succumbed to climate stress, integrating crops and livestock enabling manure transfers improving soil fertility while livestock consumed crop residues, and incorporating drought-tolerant crops like sorghum and millet alongside moisture-sensitive maize. Resource management strategies (2 mentions, 14%) reflected attempts to apply traditional conservation practices including selective harvesting where collectors took partial rather than complete plant materials enabling regeneration, rotational collection allowing sites to recover between harvest events, and deliberate retention of seed-bearing individuals ensuring species regeneration.

However, resource management faced constraints including intensifying scarcity pressures overriding sustainability concerns when immediate survival needs compelled maximum extraction, limited traditional knowledge transmission as younger women lacked detailed understanding of sustainable harvesting protocols, and open-access tenure undermining individual conservation efforts when resources managed communally without exclusion mechanisms.

The documentation of 89 plant species with complete Maa nomenclature, detailed use knowledge, and traditional management understanding represented substantial intellectual capital providing adaptive capacity foundation. This knowledge enabled identification of alternative resources when preferred species unavailable, recognition of seasonal patterns guiding collection timing, sustainable harvesting techniques preventing resource depletion, and climate change detection through observation of phenological and distribution shifts.

However, traditional knowledge faced critical limitations under novel climate conditions exceeding historical experience ranges. Traditional climate indicators developed under historical rainfall and temperature patterns proved unreliable when climate shifted beyond variability ranges upon which knowledge was based. Elders reported that "traditional weather prediction methods no longer work" because environmental signals (bird behaviors, plant flowering, cloud patterns) no longer correlated reliably with subsequent weather due to altered atmospheric conditions. This knowledge disruption created adaptation paradox where communities possessed sophisticated environmental knowledge but couldn't reliably apply it under unprecedented conditions, while simultaneously lacking access to modern climate information services that could complement traditional knowledge providing seasonal forecasts based on meteorological models.

Physical, human, and financial capital provided additional adaptive capacity though constrained by poverty and inequality. Livestock holdings averaged 8.3 Tropical Livestock Units (TLU) per household (where 1 TLU = 250 kg live weight equivalent, approximately 1 cow or 10 goats), providing mobile wealth that could be sold during emergencies, milk production for household nutrition and income, and draft power for agricultural operations.

However, livestock vulnerability to drought meant this asset base could be rapidly depleted during climate extremes, with some households reporting 50-70% livestock mortality during 2017 drought. Furthermore, livestock ownership distribution proved highly uneven with some households possessing 15-20+ TLU while others owned 1-3 TLU or no livestock, creating substantial adaptive capacity inequality.

Land ownership (67% with secure tenure) provided production base and potential collateral for credit, though land fragmentation through subdivision among heirs created parcels averaging only 2-5 acres often inadequate for sustainable mixed farming or pastoralism. Lack of secure tenure (33% without clear ownership documentation) severely constrained adaptive capacity through preventing collateral use for credit, limiting investment incentives (why improve land that might be claimed by others?), and blocking participation in some development programs requiring land ownership documentation.

Human capital through formal education (40% primary, 20% tertiary) enabled literacy supporting access to written agricultural information, numeracy facilitating market transactions and financial management, and employment opportunities providing income diversification pathways. However, limited secondary education completion (17%) constrained access to formal sector employment requiring qualifications beyond primary schooling.

Traditional skills including plant identification, sustainable harvesting, traditional medicine, handicraft production, and livestock management represented important human capital particularly valuable in contexts where formal employment opportunities proved scarce. However, intergenerational transmission weakening threatened to erode this capital as younger women acquired formal education but not traditional knowledge.

Financial capital remained severely limited with minimal cash savings among most households, limited access to formal credit from banks requiring collateral and steady income unavailable to most pastoral households, and dependence on informal credit from shopkeepers or relatives often carrying unfavorable terms. This financial capital scarcity constrained adaptive capacity by preventing investment in productive assets (improved livestock, agricultural inputs, and water storage), forcing distress sales of assets during emergencies rather than bridging temporary shortfalls through credit, and limiting ability to experiment with new adaptation strategies requiring upfront investment.

The overall adaptive capacity index of 10.4 indicated strong community-level adaptive capacity that provided substantial resilience against climate and biodiversity threats. However, this aggregate metric masked important household-level heterogeneity where well-resourced households with diverse income sources, adequate livestock holdings, strong social networks, and formal education possessed adaptive capacity scores potentially 15-18, while resource-poor households lacking these assets scored 6-8 creating vulnerability despite overall community capacity appearing adequate.

Furthermore, adaptive capacity proved dynamic rather than static, declining during prolonged stress periods as resources depleted (livestock sold during droughts, savings exhausted, social networks strained by widespread need) and recovering during favorable periods when resources could be rebuilt. The trajectory of adaptive capacity—whether increasing through development interventions and favorable conditions or declining through sustained climate stress and asset erosion—would fundamentally shape future vulnerability outcomes.

4.5.4 Integrated Vulnerability Assessment

The Climate Vulnerability Index (CVI) integrating exposure, sensitivity, and adaptive capacity components provided composite vulnerability metric enabling comparison across communities and temporal tracking (Table 4.16). The calculation followed Hahn et al. (2009) framework where vulnerability emerges from interaction among three components rather than simple summation.

Table 4.16: Climate Vulnerability Index Calculation and Component Analysis

Component	Raw Value	Standardized Index (0-10 scale)	Weight in CVI	Component Interpretation	Primary Drivers
Climate Exposure	Multiple hazards	2.2	1.0	Moderate exposure	Temperature warming (+0.35°C/decade), Precipitation variability (CV=31.2%), Extreme events (frequency increasing)
Plant-Based Sensitivity	89 species, multiple use categories	3.8	1.0	High sensitivity	Medicinal plants (36% of flora, high climate sensitivity), Construction timber (critical scarcity), Fodder species (drought vulnerability), 31 species in single locations (35% of flora)
Community Adaptive Capacity	Social capital + traditional knowledge + assets	10.4	1.0	Strong capacity	Cooperatives (8 active), Table banking (6 groups), Traditional knowledge (89 species documented), Livestock assets (8.3 TLU/household mean)
Climate Vulnerability Index (CVI)	—	**4.4**	—	**Moderate vulnerability**	**AC - (E + S) = 10.4 - (2.2 + 3.8) = 4.4**

Positive CVI values indicate adaptive capacity exceeds combined exposure and sensitivity, suggesting resilience exists though may prove inadequate if stresses intensify. The moderate vulnerability classification (CVI=4.4) indicates communities possess substantial coping capacity but remain vulnerable to sustained or extreme climate stresses that could overwhelm available adaptive mechanisms.

The CVI value of 4.4 indicated moderate vulnerability where Maasai women's livelihoods faced real climate and biodiversity threats but possessed adaptive capacity providing substantial buffering. This moderate classification suggested current conditions remained within coping range though sustained intensification of climate stresses or erosion of adaptive capacity assets could tip communities into high vulnerability requiring external assistance for survival.

Several key insights emerged from the integrated vulnerability assessment:

First is the adaptive capacity which provides critical buffering. Despite moderate climate exposure (2.2) and high plant-based sensitivity (3.8), strong adaptive capacity (10.4) maintained positive CVI indicating resilience exceeded vulnerability. The difference between combined exposure + sensitivity (6.0) and adaptive capacity (10.4) represented "resilience margin" of 4.4 units that could absorb additional stresses before vulnerability exceeded capacity. This finding validated community-based adaptation approaches emphasizing strengthening existing adaptive mechanisms (cooperatives, traditional knowledge, social networks) rather than solely attempting to reduce exposure or sensitivity which often proved difficult given limited control over climate trends and biodiversity patterns.

Second is the vulnerability distribution which masks household heterogeneity. The community-level moderate vulnerability masked extreme household variation where resource-rich households with diverse income sources, adequate livestock, strong social connections, and formal education potentially experienced low vulnerability (CVI 6-8), while resource-poor households lacking these assets faced high vulnerability (CVI 1-3) requiring immediate support. This heterogeneity created equity concerns where aggregate indicators suggested moderate vulnerability potentially obscuring critical situations among most marginalized households. Targeting adaptation support required disaggregating community averages to identify and support most vulnerable households rather than assuming community-wide moderate vulnerability meant all households adequately coped.

Third is temporal vulnerability dynamics. Vulnerability proved dynamic rather than static, fluctuating with environmental conditions and asset trajectories. During favorable periods (adequate rainfall, good harvests, livestock productivity high), adaptive capacity strengthened through resource accumulation enabling CVI increases toward 5-6. During stress periods (droughts, crop failures, livestock mortality), adaptive capacity declined through asset depletion potentially dropping CVI to 2-3 creating high vulnerability even among typically resilient households. The 2017 extreme drought exemplified this temporal dynamic where sustained climate stress depleted livestock holdings, exhausted savings, strained social networks through widespread simultaneous need, and potentially reduced CVI by 2-3 points creating temporary high vulnerability even in normally moderate-vulnerability communities.

Fourth is the thresholds and non-linear responses. Vulnerability exhibited threshold dynamics where gradual stress increases produced manageable impacts until critical thresholds crossed triggering rapid livelihood deterioration. For instance, successive years of below-average rainfall might be coped with through savings drawdown, reduced consumption, and asset sales, but third or fourth consecutive drought year could exhaust all coping mechanisms simultaneously triggering collapse requiring humanitarian assistance. Similarly, plant biodiversity loss might proceed gradually with modest impacts as women substituted alternative species or traveled farther for collection, but crossing critical threshold where no alternatives existed (last medicinal plant disappearing, final timber species exhausted) could trigger abrupt livelihood crisis eliminating essential functions.

Finally is the gender amplification of vulnerability. While CVI represented household-level vulnerability, gender analysis revealed women experienced disproportionate impacts through their specific roles and responsibilities. Climate and biodiversity stresses concentrated on women through increased resource collection labor (water, fuelwood, wild plants), healthcare responsibilities when medicinal plants scarce forcing difficult care-seeking decisions, household food provisioning obligations creating nutritional stress when women prioritized children's feeding over their own, and construction/maintenance duties when building materials scarce. Furthermore, structural gender inequalities constrained women's adaptive capacity through limited control over household resources despite bearing primary responsibility for resource management, restricted mobility reducing livelihood diversification options, excluded participation in decision-making about adaptation strategies, and limited formal education constraining employment alternatives.

The integration of gender analysis with CVI revealed that household moderate vulnerability often translated to women's high vulnerability when accounting for gendered burden distributions, suggesting gender-responsive adaptation programming essential even in moderate-vulnerability contexts.

The moderate vulnerability finding (CVI=4.4) suggested several strategic priorities for intervention and policy development. First, strengthening existing adaptive capacity offered more efficient pathways than creating entirely new institutions. Communities already possessed substantial social capital through cooperatives, table banking groups, and women's organizations providing proven platforms for collective action.

Interventions should build cooperative capacity through business training, market linkages, and bulk credit access. Traditional knowledge systems, despite erosion, retained valuable observational capacity that could be integrated with climate science through participatory monitoring networks and hybrid forecasting systems. Asset-building programs strengthening livestock holdings, land tenure security, and savings could enhance adaptive capacity without requiring complex institutional innovations.

Second, targeting most vulnerable households through poverty-focused interventions addressed the reality that moderate community-level vulnerability masked extreme household heterogeneity. Resource-poor women faced compounding constraints including lack of credit access, limited education, insecure land tenure, and absence of social protection. Interventions addressing these constraints through microfinance, adult literacy programs, land tenure reform, and social safety nets could reduce extreme vulnerability among most marginalized households.

Third, monitoring vulnerability trajectories over time would track whether adaptive capacity strengthened or declined, providing early warning of transitions from moderate to high vulnerability. Repeat assessments every three to five years using consistent methodologies would identify concerning trends including asset depletion, knowledge erosion acceleration, or increasing food insecurity, enabling proactive intervention before moderate vulnerability escalated to crisis.

Fourth, preparing for threshold crossings acknowledged that some climate or biodiversity changes might push systems beyond adaptation capacity. Developing contingency plans for complete timber depletion, key medicinal plant extinctions, or prolonged multi-year droughts would enable managed rather than crisis-driven transitions. Anticipating potential threshold scenarios and planning appropriate responses would prevent reactive measures implemented under crisis conditions.

Fifth, mainstreaming gender considerations throughout adaptation programming ensured interventions addressed women's specific vulnerabilities while building on their knowledge and capabilities. Gender-responsive programming required assessing gender-differentiated impacts during design, ensuring women's meaningful participation, targeting resources explicitly to women, addressing structural constraints including mobility restrictions and property rights, and monitoring gender equity outcomes. This approach recognized that effective adaptation required transforming gender inequalities that themselves constituted sources of vulnerability.

CHAPTER FIVE

DISCUSSION

5.1 Introduction

This chapter interprets findings from Chapter Four, comparing results with existing literature while examining broader implications for climate adaptation, biodiversity conservation, and gender equity in pastoral contexts. Discussion is organized by the four study objectives, followed by integrated synthesis and study limitations.

5.2 Climate Trends and Their Implications

5.2.1 Temperature Warming Patterns

The observed warming rate of 0.35°C per decade significantly exceeds the global average of 0.18°C per decade (IPCC, 2021), confirming amplified warming in semi-arid East Africa. This enhanced warming aligns with Gebrechorkos et al. (2023) findings that temperature increases across East Africa exceed global averages due to reduced evapotranspiration, altered land-atmosphere energy exchanges, and positive feedbacks linking vegetation loss and temperature increases. Reduced evapotranspiration means less energy dissipated through latent heat flux, leaving more energy for direct air temperature increase. This mechanism operates particularly strongly during dry seasons when vegetation wilts and soil moisture depletes, explaining why July-August showed strongest warming trends despite being traditionally cool months.

The 2017 extreme event (19.15°C annual mean, +2.35°C above baseline) demonstrates that warming manifests through increasingly intense extremes potentially exceeding adaptation thresholds. Lyon and DeWitt (2012) documented that East African droughts typically coincide with temperature anomalies, creating compound stress where heat and moisture deficits interact synergistically. The 2017 event combined exceptional warmth with severe precipitation deficit, creating cascading impacts including crop failures, livestock mortality, and acute food insecurity (Uhe et al., 2018).

For Maasai women's livelihoods, warming creates multiple stress pathways including direct heat stress reducing labor capacity, livestock heat stress reducing milk production affecting household nutrition and income, and plant phenology disruption potentially disconnecting traditional harvest calendars from actual resource availability peaks.

5.2.2 Precipitation Variability and Seasonality Shifts

The coefficient of variation for annual precipitation (31.2%) indicates extremely high inter-annual variability exceeding typical semi-arid ranges (20-30%), creating persistent uncertainty for livelihood planning. This aligns with Gebrechorkos et al. (2023) projections that hydrological extremes will intensify across East Africa, creating whiplash conditions alternating between moisture deficit and excess. The lack of significant directional trend in annual precipitation ($\tau=0.087$, $p=0.498$) despite substantial decadal fluctuations confirms that precipitation trends remain less consistent than temperature trends (Nicholson, 2017). However, significant seasonal shifts—September precipitation increasing ($\tau=0.338$, $p=0.009$) while February decreasing ($\tau=-0.251$, $p=0.054$)—indicate fundamental transformation of seasonal rainfall distribution with potentially greater consequences than changes in annual totals. The September increase extends the wet season beyond traditional October-December period, promoting pest and disease cycles, delaying land preparation, and disrupting traditional transhumance patterns. The February decrease delays long rains onset, shortening growing seasons and creating acute planting timing uncertainty.

Community perceptions validated these seasonal shifts with remarkable precision (87% reporting changed rainfall timing), demonstrating that traditional ecological observations detect climate changes accurately. However, women reported that "traditional weather prediction methods no longer work" because environmental signals that previously correlated with subsequent rainfall now occur without expected precipitation, creating knowledge crisis where communities possess sophisticated monitoring capabilities but can't confidently act on observations. The increased frequency of heavy rainfall events (doubling from 2.3 to 4.8 events/year) combined with extended dry spells creates challenging conditions where total precipitation may remain adequate while agricultural productivity declines due to temporal distribution problems. Intense storms generate runoff rather than soil infiltration, causing soil erosion while wasting water.

5.2.3 Validation of Traditional Climate Observations

The strong correspondence between women's climate perceptions and meteorological measurements (mean scores >4.0/5.0) provides empirical support for incorporating traditional ecological knowledge into climate monitoring. This validates Barberstock (2024) arguments that indigenous observations provide accurate environmental monitoring particularly valuable for detecting local-scale changes. Mechanisms enabling accurate perception include daily environmental interaction creating extensive observational opportunities, multi-generational knowledge transmission providing historical baselines, holistic ecosystem observation detecting changes through multiple environmental responses, and livelihood impact sensitivity where climate changes affecting daily activities create tangible feedback.

However, the breakdown of traditional forecasting systems highlights critical distinction between detection and prediction. Women accurately detect realized changes but traditional forecasting developed to predict future conditions has broken down because novel climate conditions exceed historical experience ranges. This creates urgent need for integrating traditional observations with scientific climate forecasting through genuine partnership respecting both knowledge systems' strengths (Vincent et al., 2018).

5.3 Plant Biodiversity Patterns and Dependencies

5.3.1 Species Diversity in Comparative Context

The documentation of 89 species across 33 families represents substantial biodiversity comparable to other semi-arid pastoral systems in East Africa (typical range 60-120 species). The Shannon-Weiner Diversity Index (H'=1.335) indicates moderate diversity typical for semi-arid ecosystems (range 1.2-2.5) where climatic constraints limit species numbers. The family: species ratio (1:2.7) indicates relatively high phylogenetic diversity suggesting functionally diverse assemblage providing ecosystem resilience. However, moderate diversity indices should not obscure critical vulnerability: 35% of species exist in single locations creating extreme localized extinction risk inadequately captured by standard diversity metrics.

5.3.2 Critical Conservation Concerns

The finding that 31 species (35%) exist in single locations with three species persisting as single individuals represents conservation emergency requiring immediate intervention. This concentrated vulnerability aligns with broader patterns across African ecosystems where climate change threatens major woody species through range contractions, recruitment failure, and mortality during extreme events (Kapuka et al., 2022). Single-individual persistence likely results from multiple interacting factors: historical overharvesting reducing formerly larger populations, range margin populations where Narok County falls outside optimal climatic envelopes, browsing pressure preventing seedling establishment, climate conditions exceeding species' tolerance ranges, and potential genetic bottlenecks affecting remaining individuals. The local extinction of four species within living memory demonstrates biodiversity loss is ongoing process already eliminating species remembered by current community members. Particularly concerning is that younger women remained entirely unfamiliar with extinct species, creating cultural amnesia where biodiversity decline eliminates both biological resources and traditional knowledge simultaneously (Fernández-Llamazares et al., 2022).

5.3.3 Medicinal Plant Dependencies and Healthcare

Medicinal applications dominated traditional plant use (32 species, 36% of flora) with high climate sensitivity, creating critical healthcare vulnerability. This heavy dependence reflects global patterns where rural populations rely on traditional medicine for 70-80% of primary healthcare due to limited access to modern facilities, unaffordable pharmaceuticals, and demonstrated effectiveness of plant-based remedies (Nankaya et al., 2019). However, climate change threatens medicinal flora through multiple mechanisms extending beyond mortality. Alum et al. (2024) demonstrated that rising temperatures and altered precipitation affect bioactive compound profiles, creating dual vulnerability through both species loss and reduced pharmaceutical quality of persisting populations. The concentration of medicinal knowledge among elderly women (100% of elders knowing all 32 species versus only 38% of young women) combined with 72% preparation knowledge loss creates intergenerational crisis. This dual erosion—simultaneous loss of medicinal plants and medicinal knowledge—creates healthcare vulnerability more severe than either loss alone.

5.3.4 Multi-Purpose Species and Livelihood Functions

Seven Acacia species collectively representing 22.61% of relative frequency demonstrate extraordinary importance for multiple simultaneous functions. This aligns with broader patterns across African drylands where Acacia species provide integrated services including fodder, shade, firewood, construction materials, medicinal compounds, and nitrogen fixation (Syampungani et al., 2023). Multi-purpose species loss eliminates several livelihood supports simultaneously, requiring finding separate substitutes for multiple distinct functions—an extremely difficult proposition. The 2017 drought reportedly caused substantial Acacia mortality particularly among younger trees, with seedling and sapling mortality preventing population regeneration.

5.3.5 Biodiversity Loss and Cultural Erosion

The documentation of local extinctions and younger women's complete unfamiliarity with extinct species highlights cultural dimensions of biodiversity decline. Beyond material resource loss, species extinctions eliminate cultural knowledge, traditional practices, linguistic diversity, and cultural identity elements (Fernández-Llamazares et al., 2022).

Ficus thonningii existing as single individual while serving essential ceremonial functions exemplifies how biodiversity loss threatens cultural practices. The loss of this individual would force communities to either abandon traditional ceremonies or travel long distances to regions where *Ficus* persists, creating substantial costs. This intangible heritage loss represents cultural dimension rarely captured in ecological assessments but potentially as consequential for community wellbeing as material impacts.

5.4 Vulnerability Dynamics and Adaptation

5.4.1 Gendered Vulnerability Pathways

The Climate Vulnerability Index (CVI=4.4) indicating moderate overall vulnerability masks substantial gender-differentiated impacts where women experience disproportionate burdens through their specific roles. This aligns with extensive literature documenting systematically differentiated climate impacts by gender (Adeola et al., 2024). The gendered vulnerability pathways, concentrated exposure through resource collection, intensified caregiving burdens, restricted mobility limiting adaptation options, excluded decision-making participation, reflect patterns identified across African pastoral contexts. Gebre et al. (2018) documented remarkably similar dynamics among Afar pastoralists where women's water and fuelwood collection burdens intensified during droughts while men pursued livestock migration.

The pattern that "women searched for water while men migrated" exemplifies gendered adaptation where mobility remained culturally acceptable for men while women's restricted mobility confined them to degraded local environments. Physical health impacts including premature aging, back problems, and general health deterioration align with research documenting chronic health consequences from increased resource collection distances (Sorenson et al., 2011). However, the study also documented women's agency through cooperatives, traditional knowledge, social networks, and diverse livelihood strategies, challenging deficit-focused narratives portraying women solely as victims (Ojong et al., 2024).

5.4.2 Social Capital and Resilience Assets

The overall adaptive capacity index of 10.4 validates arguments that social capital provides critical resilience resource (Pinho-Gomes & Woodward, 2024). Cooperatives represented strongest adaptation mechanism (47%), providing resource pooling, collective bargaining, market access, and coordinated emergency responses. Table banking groups providing rotating savings and credit represented particularly important financial resilience mechanism for women lacking formal banking access. However, small loan sizes (5,000-30,000 KES) while adequate for minor investments prove insufficient for major livelihood transformations, suggesting need for complementary larger-scale credit access.

Traditional knowledge (89 species documented) represented substantial intellectual capital, though severe erosion (retention ratios 0.20-0.45) threatens elimination within one generation. Livestock holdings averaged only 8.3 TLU per household substantially below 15-20 TLU considered adequate for pastoral security with highly uneven distribution creating adaptive capacity inequality.

5.4.3 Barriers to Effective Adaptation

Despite substantial adaptive capacity, multiple structural barriers constrained women's adaptation. Limited financial capital prevented adaptation investments despite recognized beneficial strategies. Systematic gender inequalities meant even well-resourced households often failed to adopt women-identified strategies due to women's limited decision-making authority. Extension services accessed by only 3% despite being potentially most valuable information source reflected both resource constraints and gender barriers. Limited formal education constrained employment opportunities. Land tenure insecurity (33% lacking documentation) created adaptation barriers through prevented collateral use and limited investment incentives. The breakdown of traditional climate indicators created knowledge barrier preventing confident decision-making, with radio forecasts proving "often wrong for our specific area" while extension remained inaccessible, leaving women "guessing" about appropriate management decisions.

5.5 Knowledge Systems and Climate Awareness

5.5.1 Information Access and Quality

Radio broadcasting dominance (67%) reflected its advantages for rural populations but created vulnerability through single-channel over-dependence. Critical gaps in agricultural extension (3% access) and mobile-based services (2% access) reflected systemic underinvestment. However, simply expanding information dissemination without addressing quality, relevance, and actionability constraints risks providing more information without improving decision-making. Available information suffered from accuracy problems, timeliness limitations, and relevance gaps. The gender digital divide where rural women are 49% less likely than urban women to use mobile internet (GSMA, 2023) created additional barrier, reflecting women's lower incomes, lower literacy, and social norms where husbands controlled household phones.

5.5.2 Traditional Knowledge under Climate Change

Extensive traditional knowledge (89 species documented) validated arguments that traditional knowledge represents invaluable intellectual capital (UN, 2024). However, the study revealed troubling paradox: while traditional knowledge provided accurate climate change detection, traditional forecasting systems broke down under novel conditions exceeding historical experience ranges. This breakdown represents epistemological crisis where knowledge validity criteria become questioned. When novel climate conditions decouple indicators from outcomes, validation mechanisms break down, creating uncertainty about which traditional knowledge remains valid versus which requires revision. This creates urgent need for "adaptive traditional knowledge" maintaining valuable understanding while updating practices based on contemporary conditions.

5.5.3 Intergenerational Knowledge Transmission

Severe knowledge erosion across multiple domains (retention ratios 0.20-0.45) represents cultural dimension of climate impacts rarely quantified. Climate indicator knowledge suffered 80% loss while medicinal preparation knowledge experienced 72% loss, demonstrating cultural impacts may prove as consequential as biophysical impacts. Transmission barriers included reduced practice frequency as commercial substitutes were adopted, knowledge system disruption under novel conditions, generational value differences, time constraints, and geographic separation through migration. These barriers reflect broader cultural change patterns, though climate-driven dimension proves particularly concerning as environmental changes actively undermine traditional knowledge reliability.

However, transmission disruption isn't inevitable. Construction knowledge showed "declining but functional" status, suggesting knowledge domains critical for daily practice maintain better transmission. Strategic interventions could strengthen transmission through structured learning opportunities, accessible documentation, formal school curriculum integration, and economic incentives.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 Climate Trends

Analysis revealed statistically significant warming of 0.35°C per decade ($\tau=0.312$, $p=0.008$), nearly double the global average, with the 2017 extreme event (+2.35°C above baseline) demonstrating that warming manifests through increasingly intense extremes. Precipitation showed extremely high variability (CV=31.2%) without directional trends in annual totals but critical seasonal shifts—September increasing significantly (+47%) while February decreasing (-33%)—fundamentally transforming bimodal rainfall patterns. Heavy rainfall events and extended dry spells both doubled from 1990s to 2010s, creating climate whiplash alternating between moisture extremes. Maasai women's climate perceptions validated meteorological measurements with remarkable precision, though traditional forecasting systems broke down under novel conditions.

6.1.2 Plant Biodiversity

Comprehensive surveys documented 89 species across 33 families (moderate diversity, $H'=1.335$) supporting diverse livelihood functions including 32 medicinal species (36% of flora), 12 construction timber species, and 7 multi-purpose Acacia species providing integrated services. Critical conservation concerns emerged: 35% of species exist in single locations creating extreme extinction vulnerability, three species persist as single individuals requiring emergency intervention, and four species documented as locally extinct within living memory. Site N4 identified as critical biodiversity refuge containing 28% of total flora requiring maximum protection against encroaching agricultural expansion.

6.1.3 Climate Vulnerability

Integrated assessment revealed moderate overall vulnerability (CVI=4.4) where strong adaptive capacity (10.4) through cooperatives, table banking, and traditional knowledge partially offset high plant-based sensitivity (3.8) and moderate climate exposure (2.2). However, substantial household heterogeneity masked critical vulnerability among resource-poor women, while structural constraints (poverty, gender inequality, limited extension access, tenure insecurity) limited adaptation effectiveness. Gender analysis revealed women's disproportionate burdens through intensified water collection (distances tripling during droughts), healthcare responsibilities with medicinal plant scarcity, and household management obligations while lacking decision-making authority.

6.1.4 Climate Awareness

Assessment revealed concerning over-dependence on radio (67%) for climate information with near-absent extension services (3%) and minimal mobile-based access (2%). Traditional knowledge assessment documented extensive knowledge (89 species) but severe intergenerational erosion (retention ratios 0.20-0.45) threatening elimination within one generation. Climate indicator knowledge suffered catastrophic 80% loss while medicinal preparation knowledge lost 72%, creating dual crisis of climate-driven disruption and transmission breakdown requiring urgent intervention and hybrid knowledge system development integrating traditional observations with scientific forecasting.

6.2 General Conclusions

The integrated analysis revealed profound interconnections among climate change, plant biodiversity loss, and gendered livelihood vulnerabilities creating cascading impacts through multiple temporal and spatial scales. Climate warming and precipitation variability drive plant biodiversity decline, which amplifies women's livelihood vulnerabilities through reduced healthcare access, infrastructure challenges, and intensified resource collection labor. These impacts concentrate disproportionately on women through their specific roles as primary resource collectors, healthcare providers, and household managers.

Despite substantial community adaptive capacity through social capital and traditional knowledge, structural barriers at multiple scales constrain effective adaptation. Traditional knowledge systems stand at critical juncture facing dual threats of climate-driven disruption and intergenerational transmission breakdown, requiring urgent intervention preventing complete loss while adapting knowledge to remain relevant under novel conditions.

The magnitude of documented changes raises fundamental questions about whether incremental adaptation within existing livelihood systems proves adequate or whether transformational changes become necessary. Successful navigation requires supporting both pathways—strengthening traditional systems where viable while enabling managed transformations where necessary—allowing communities to make informed choices about futures rather than being driven by crisis into maladaptive outcomes.

6.3 Recommendations

6.3.1 Climate Trends Analysis

Develop hybrid climate information systems integrating traditional climate indicators with scientific forecasts through participatory monitoring networks, downscaling regional climate models to local microclimates accounting for Narok's topographic diversity, and establishing diverse information channels (mobile services, community radio programs, extension services) that reach women in culturally appropriate formats. Link climate information to actionable resources including seeds, credit, and inputs enabling women to act on forecasts received, while training community members in interpreting probabilistic forecasts and distinguishing climate versus weather predictions.

6.3.2 Plant Biodiversity Documentation

Implement emergency conservation for critically endangered species through immediate seed collection and nursery propagation for single-individual species (*Podocarpus latifolius*, *Ficus thonningii*, *Osyris lanceolata*), establish community conservancies protecting Site N4 and other biodiversity hotspots with benefit-sharing mechanisms ensuring local stewardship, and create medicinal plant gardens near homesteads cultivating threatened species for household use. Conduct systematic ethnobotanical research documenting extinct species knowledge from elders (60+ years) before knowledge holders pass away, survey neighboring regions for surviving populations of locally extinct species, and explore domestication potential for threatened wild species transitioning them to managed cultivation.

6.3.3 Vulnerability Assessment

Strengthen existing adaptive capacity through business training and bulk credit access for women's cooperatives, expand table banking networks providing larger loan sizes (50,000-100,000 KES) enabling transformative investments, and secure land tenure through accelerated adjudication with joint titling for married couples and inheritance rights for widows. Target poverty-focused interventions addressing specific constraints facing resource-poor women including microfinance tailored to women's needs, adult literacy and skills training enabling livelihood diversification, and social safety nets buffering climate shocks for most vulnerable households.

6.3.4 Climate Knowledge Assessment

Massively expand agricultural extension services through recruitment of female extension officers (targeting 50% female representation within 5 years), training in gender-responsive approaches and pastoral systems, mobile extension teams conducting regular circuits to remote settlements, and group-based extension through women's cooperatives reducing individual visit requirements**.** Integrate traditional knowledge into formal education through culturally relevant curricula incorporating local plant knowledge as science content, community elders as visiting teachers, school gardens featuring indigenous species, and Maa language teaching materials validating traditional knowledge as legitimate knowledge system alongside modern science.

6.3.5 Cross-Cutting Recommendations

Mainstream gender throughout all interventions ensuring climate adaptation programs assess gender-differentiated impacts during design, guarantee women's meaningful participation through quotas and women-only programs, allocate gender-responsive budgets, address structural inequalities including property rights and mobility restrictions, and monitor gender equity outcomes alongside aggregate metrics.

Establish longitudinal monitoring systems repeating vulnerability assessments every 3-5 years using consistent methodologies, tracking key indicators (species abundance, climate trends, household assets, knowledge retention), evaluating intervention effectiveness, and providing early warning when moderate vulnerability threatens to escalate toward crisis requiring emergency rather than development response.

6.4 Contribution to Knowledge

This study has made significant contributions: (1) Empirical contributions through comprehensive integrated dataset (30-year climate analysis, 89 species documentation, 100 household vulnerability assessment, traditional knowledge analysis) rarely achieved in pastoral research; (2) Methodological contributions demonstrating convergent mixed-methods effectiveness and validating traditional climate observations against meteorological data; (3) Theoretical contributions advancing climate vulnerability theory by demonstrating plant-based sensitivity as critical pathway linking climate to livelihoods and documenting temporal vulnerability cascades; (4) Policy contributions providing evidence base for gender mainstreaming, community-based biodiversity conservation, extension expansion, and hybrid climate information systems.

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APPENDICES

Appendix I: Questionnaire

Household Questionnaire: Maasai Women's Plant Biodiversity Use and Climate Change Perceptions

Section A: Household Demographics and Background

A1. Location (Village/Settlement): ________________

A2. Interview Date: ________________

A3. Respondent's age: ________________

A4. Respondent's role in household:

- Household head
- Spouse of household head
- Adult daughter
- Other (specify): ________________

A5. Total household size: ________________

A6. Number of children under 18: ________________

A7. Highest level of education completed:

- No formal education
- Primary school
- Secondary school
- Post-secondary
- Other (specify): ________________

A8. Primary livelihood activities (check all that apply):

- Pastoralism (livestock keeping)
- Agriculture/farming
- Small business/trade

- Wage employment
- Other (specify): _________________

A9. Livestock owned by household:

- Cattle: _______ head
- Goats: _______ head
- Sheep: _______ head
- Other: _________________

Section B: Plant Biodiversity Use and Reliance

B1. How often do you collect wild plants for household use?

- Daily
- Several times per week
- Weekly
- Monthly
- Rarely
- Never

B2. What are the main purposes for which you use wild plants? (Check all that apply)

- Food/nutrition
- Traditional medicine
- Construction materials
- Fuel/firewood
- Livestock fodder
- Handicrafts/tools
- Cultural/ceremonial purposes
- Income generation
- Other (specify): _________________

B3. Please list the 5 most important plant species your household depends on:

Plant Name (Local)	Plant Name (English/Swahili if known)	Primary Use	Collection Frequency
1.			
2.			
3.			
4.			
5.			

B4. Who in your household is primarily responsible for plant collection?

- Adult women
- Adult men
- Children (boys)
- Children (girls)
- Everyone equally
- Other (specify): _________________

B5. How far do you typically travel to collect plants?

- Less than 1 km from home
- 1-3 km from home
- 3-5 km from home
- More than 5 km from home

B6. Has the time spent collecting plants changed over the past 5 years?

- Much more time needed
- Somewhat more time needed

- About the same
- Somewhat less time needed
- Much less time needed

B7. What percentage of your household's food comes from wild plants?

- 0-10%
- 11-25%
- 26-50%
- 51-75%
- More than 75%

B8. What percentage of your household's medicine comes from traditional plants?

- 0-10%
- 11-25%
- 26-50%
- 51-75%
- More than 75%

B9. Do you earn income from selling plants or plant products?

- Yes, regularly
- Yes, occasionally
- No, but have in the past
- No, never

B10. If yes to B9, approximately how much income per month: ________________

Section C: Observed Changes in Plant Availability

C1. Have you noticed changes in the availability of important plants over the past 10 years?

- Yes, many plants less available

- Yes, some plants less available
- No significant change
- Yes, some plants more available
- Yes, many plants more available

C2. Which plants have become harder to find? (List up to 5)

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

C3. What do you think are the main reasons for plant scarcity? (Check all that apply)

- Less rainfall
- More frequent droughts
- Overgrazing by livestock
- Land conversion for agriculture
- Urban development
- Overharvesting
- Pests and diseases
- Soil degradation
- Other (specify): _________________

C4. Have you had to travel further to find certain plants?

- Yes, much further
- Yes, somewhat further
- No change
- Actually, closer now

C5. Have you changed which plants you use due to availability?

- Yes, frequently
- Yes, sometimes
- Rarely
- Never

Section D: Adaptive Strategies and Vulnerability

D1. When important plants become scarce, what do you do? (Check all that apply)

- Travel further to collect
- Use alternative plant species
- Purchase from market instead
- Reduce consumption
- Ask relatives/neighbours for help
- Store more when available
- Try to cultivate the plants
- Nothing/go without
- Other (specify): ________________

D2. Do you grow any traditional plants in your homestead?

- Yes, many varieties
- Yes, a few varieties
- No, but interested
- No, not interested

D3. If yes to D2, which plants do you cultivate?

D4. What prevents you from cultivating more traditional plants? (Check all that apply)

- Lack of water
- Lack of space

- Lack of knowledge
- Lack of seeds/seedlings
- Too much work
- Animals destroy crops
- Cultural restrictions
- Nothing prevents me
- Other (specify): ________________

D5. Have you learned about new plants or uses from others recently?

- Yes, frequently
- Yes, sometimes
- Rarely
- Never

D6. Do you share plant knowledge with younger women in your community?

- Yes, regularly
- Yes, sometimes
- Rarely
- Never

D7. How well do younger women (under 30) know about traditional plants compared to older women?

- Much better knowledge
- Somewhat better
- About the same
- Somewhat less knowledge
- Much less knowledge

D8. What would help your household be less vulnerable to plant scarcity? (Check all that apply)

- Better water sources
- Protected areas for plants
- Training on cultivation
- Access to seeds/seedlings
- Alternative livelihood options
- Better roads for access
- Community rules on harvesting
- Government support
- Other (specify): ________________

Section E: Climate Change Knowledge and Perceptions

E1. Have you heard the term "climate change"?

- Yes, understand it well
- Yes, heard but don't understand
- No, never heard of it

E2. In your own words, what do you think climate change means?

E3. Have you noticed changes in weather patterns over the past 10 years?

- Yes, major changes
- Yes, some changes
- No significant changes
- Unsure

E4. What weather changes have you observed? (Check all that apply)

- Less total rainfall

- More unpredictable rainfall timing
- Longer dry seasons
- Shorter rainy seasons
- More intense storms
- Higher temperatures
- More frequent droughts
- Unusual weather events
- Other (specify): ________________

E5. How do these weather changes affect plant availability?

- Very negatively
- Somewhat negatively
- No effect
- Somewhat positively
- Very positively

E6. What do you think causes changes in weather/climate? (Check all that apply)

- Natural cycles
- God's will
- Human activities
- Pollution
- Deforestation
- Industrial activities
- Don't know
- Other (specify): ________________

E7. How concerned are you about future climate changes?

- Very concerned
- Somewhat concerned
- Not very concerned
- Not concerned at all

E8. Do you think your community can adapt to climate changes?

- Yes, very well
- Yes, with some difficulty
- No, will be very difficult
- No, impossible to adapt

E9. Where do you get information about weather and climate? (Check all that apply)

- Radio
- Television
- Mobile phone
- Government extension officers
- Community meetings
- Religious leaders
- Traditional weather forecasters
- Neighbours/relatives
- Own observations
- Other (specify): ________________

E10. Have you made any changes to your livelihood practices because of climate concerns?

- Yes, major changes
- Yes, minor changes

- Planning to make changes
- No changes made

E11. If yes to E10, what changes have you made?

Section F: Community and Support Systems

F1. How strong is cooperation among women in your community for plant collection and use?

- Very strong
- Somewhat strong
- Weak
- Very weak

F2. Are there community rules about plant harvesting?

- Yes, formal rules enforced
- Yes, informal guidelines followed
- No, everyone collects freely
- Don't know

F3. Who would you turn to for help if plants became very scarce?

- Family members
- Neighbours
- Community leaders
- Government agencies
- NGOs
- Religious organizations
- No one
- Other (specify): _________________

F4. What support would be most helpful for maintaining plant resources? (**Choose top 3**)

- Community conservation areas
- Training on sustainable harvesting
- Help with cultivation
- Water sources for plants
- Alternative income sources
- Better transportation
- Youth education programs
- Other (specify): _________________

Section G: Additional Comments

G1. What is your biggest concern about plant resources for the future?

G2. What would you like to see done to protect important plants?

G3. Is there anything else you would like to share about plants, climate, or changes in your environment?

Thank you for participating in this survey. Your responses will help us better understand the challenges and opportunities for maintaining plant biodiversity in Maasai communities.

Appendix 2: Research Permit

THIS IS TO CERTIFY THAT:
MR. JOHN KISHOYIAN SINTERIA
of MOI UNIVERSITY, 0-3100 eldoret,has
been permitted to conduct research in
Narok County

on the topic: DETERMINATION OF THE VULNERABILITY AND IMPACTS OF CLIMATE CHANGE ON MAASAI WOMEN IN NARROK COUNTY

for the period ending:
1st April,2017

Permit No : NACOSTI/P/16/38430/9133
Date Of Issue : 4th April,2016
Fee Recieved :ksh 1000

Applicant's Signature

Director General
National Commission for Science,
Technology & Innovation

CONDITIONS

1. You must report to the County Commissioner and the County Education Officer of the area before embarking on your research. Failure to do that may lead to the cancellation of your permit
2. Government Officers will not be interviewed without prior appointment.
3. No questionnaire will be used unless it has been approved.
4. Excavation, filming and collection of biological specimens are subject to further permission from the relevant Government Ministries.
5. You are required to submit at least two(2) hard copies and one(1) soft copy of your final report.
6. The Government of Kenya reserves the right to modify the conditions of this permit including its cancellation without notice

REPUBLIC OF KENYA

NACOSTI

National Commission for Science,
Technology and Innovation

RESEARCH CLEARANCE PERMIT

Serial No. A 8401

CONDITIONS: see back page

Appendix 3: Plagiarism Awareness Certificate

SR983

ISO 9001:2019 Certified Institution

THESIS WRITING COURSE

PLAGIARISM AWARENESS CERTIFICATE

This certificate is awarded to

JOHN KISHOYIAN SINTERIA

MSC/EB/01/15

In recognition for passing the University's plagiarism

Awareness test for Thesis **entitled: CLIMATE CHANGE, PLANT BIODIVERSITY AND LIVELIHOODS AMONG MAASAI WOMEN IN NAROK COUNTY, KENYA** with similarity index of 10% and striving to maintain academic integrity.

Word count:20464

Awarded by

Prof. Anne Syomwene Kisilu

CERM-ESA Project Leader Date: 11/08/2025