School of Graduate Studies

College of Social Sciences

Department of Geography and Environmental Studies

Spatio-temporal trends of Prosopis juliflora plantation and its implications on livelihoods in Awash Fentale District, Afar region, Ethiopia

BY

TESFAYE TAYE ERENA

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirement for the Degree of Master of Arts in Geography and Environmental Studies (Specialization in Geographic Information System, Remote Sensing, and Digital Cartography)

Addis Ababa University

Addis Ababa, Ethiopia

December, 2024

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December, 2024

Statement Of Approval

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This is to certify that the thesis prepared by TESFAYE TAYE ERENA, titled with Spatio-temporal Trends of Prosopis juliflora Plantation and its implications on Livelihoods in Awash Fentale District, Afar region, Ethiopia and submitted in partial fulfillment of the requirements for the Degree of Master of Arts in GIS, Remote Sensing, and Digital Cartography complies with the regulations of the university and meets the accepted standards with respect to the originality and quality.

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Acknowledgements

I would like to extend my sincere gratitude to Dr. Asnake Mekuriaw, my advisor, for his unwavering commitment, support, and guidance throughout this research. His insightful counsel and mentorship provided me with the direction I needed to complete this thesis.
I am also deeply appreciative of my co-advisor, Dr. Telesphore Brou, for his valuable feedback, which significantly enhanced the quality of my work. I extend my heartfelt gratitude to Mr. Fanosie Mekonnin for his invaluable assistance in facilitating the data collection process. I am also grateful to Mr. Diriba Urgessa for his essential moral and technical support during the study; his expertise and encouragement were instrumental in the successful completion of this work.

I wish to acknowledge the staff of the Natural Resources Department in the Woreda of the study area for their guidance on efficient data collection techniques. I am equally grateful to Mr. Abebe Yirdawu for his technical support in the composition of this thesis.

Finally, I extend my deepest respect and appreciation to the Afar pastoralists of the study area. Their cooperation, kindness, and willingness to allow me to conduct research on their land made this study possible. I am profoundly thankful for their assistance in providing the support I needed.

Tesfaye Taye

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Glossary

AF	Awash Fentale
ANP	Awash National Park
ANN	Artificial Neural Network
ARS	Afar Regional State
AVHRR	Advanced Very High-Resolution Radiometer
CHIRPS	Climate Hazards Group Infrared Precipitation with Station data
CMK	Mann Kendall
CSA	Central Statistics Agency
DEM	Digital Elevation Model
EBI	Ethiopian Biodiversity Institute
ESA	European Space Agency
ESS	Ethiopian Statistical Service
ETM	Enhanced Thematic Mapper Plus (Landsat 7)
EVI	Enhanced Vegetation Index
FAO Wapor:	Food and Agricultural Organization Water Productivity
FGD	Focus Group Discussion
GCP	Ground Control Point
GEDI	Global Ecosystem Dynamics Investigation
GIS	Geographic Information System
GPS	Global Positioning System
GSFC	Goddard Space Flight Center (NASA)
IAS	Invasive Alien Species
KII	Key Informant Interview
LAI	Leaf Area Index
LaSRC	Land Surface Reflectance Code
LEDAPS	Landsat Ecosystem Disturbance Adaptive Processing System software

MLC	Maximum Likelihood Classification
MODIS	Moderate Resolution Imaging Spectroradiometer
MLC	Maximum Likelihood Classification
MSI	Multi-Spectral Image (Sentinel_2)
NDII	Normalized Difference Infrared Index
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
OLI	Operational Land Imagery (Landsat_8)
RF	Rainfall
RGB	Red-Green-Blue
RS	Remote Sensing
SPOT	Satellite Pour l'Observation de la Terre ("Satellite for observation of Earth")
SPSS	Statistical Package for Social Sciences
SRTM	Shuttle Radar Topography Mission
SVM	Support Vector Machine
SVI	Sentinel Improved Vegetation Index
VIs	Vegetation Indices

Abstract

Prosopis juliflora plantations has been the dominant plant species in the eastern parts of Ethiopoia. significantly impact the livelihoods of local communities. This study examines the trends and impacts of Prosopis juliflora plantations in the Awash Fentale District of the Afar region, Ethiopia. The analysis uses Landsat imagery and Sentinel-2 data on the Google Earth Engine platform, covering a 30-year period from 1993 to 2023, with data examined at ten-year intervals: 1993, 2003, 2013, and 2023. The methodology includes land use/land cover (LULC) classification, Normalized Difference Vegetation Index (NDVI) analysis, regression analysis, Mann-Kendall trend analysis, and Normalized Difference Infrared Index (NDII) computation. A comparative assessment of algorithms between Landsat 8 and Sentinel-2 for 2023 reveals that Sentinel-2 achieved higher overall accuracy (97%) and Kappa (96) compared to Landsat 8 (overall accuracy: 90%, Kappa: 88%). Statistical validation indicates the significance of these results, with a p-value of 0.0001, below the 0.05 threshold. The results of this study show a continuous increase in the area invaded by Prosopis juliflora over a 30-year period, from 1993 to 2023. Specifically, the coverage of this invasive species grew from 63 km² in 1993 to 87.3 km² in 2023, indicating significant expansion within the studied area.To assess household perceptions, a perception index was developed using a five-point Likert scale, identifying factors that outline these views. The results show about 93% of the respondents have negative perception whereas 7% of households view Prosopis juliflora positively. Given the invasive nature of Prosopis juliflora and its impact on land use and pastoral livelihoods, these findings are essential for informing policymakers and land managers to develop effective strategies for managing and mitigating its spread in the region.

Keywords: *Prosopis juliflora, spatio-temporal trends, Google Earth Engine, LULC classification, NDVI analysis, NDII computation, invasive species, pastoral livelihoods.*

CHAPTER ONE

INTRODUCTION

1.1.Background of the study

Prosopis juliflora is recognized as an extremely dominant invasive non-native plant species in numerous regions across the globe (Wakie et al., 2014, Tilahun and Asfaw 2012). The species has successfully established itself and rapidly spread throughout various tropical and subtropical regions worldwide, raising significant concerns (Shackleton et al., 2014). Prosopis juliflora demonstrates remarkable adaptability to flourish in diverse environmental circumstances, encompassing arid and semi-arid areas (Poland et al., 2021). Invasive species often possess strong abilities to disperse, grow rapidly with short generation times, and exhibit high tolerance for diverse environmental conditions (Poland et al., 2021).

Based on the findings of Degefu et al., (2022), the rapid spread of Prosopis juliflora has resulted in its encroachment upon valuable grazing and croplands, as well as residential areas. The environmental impact of Prosopis juliflora is attributed to its actions, including oxygen absorption and carbon dioxide emission, water consumption, humidity alteration, and transformation of agricultural lands into non-cultivable conditions (Vigneshkumar and Yarrakula, 2017). The species demonstrates a significant level of patch recruitment, subsequent amalgamation, and rapid spread across diverse soil types (Robinson et al., 2008). In dry and semi-arid regions, Prosopis juliflora, an evergreen shrub, is one of the most invasive species.

Prosopis juliflora is recognized for its rapid growth and ability to produce biomass (Gurumurti et al.,1984). It also possesses the capacity to fix nitrogen from the atmosphere and has the ability to thrive in arid conditions and saline soils Degefu et al., (2022). The ability to fix nitrogen is a valuable trait, as it enables the plant to convert atmospheric nitrogen into organic compounds that can be used for its growth and development. This capability allows the plant to thrive in nitrogen-deficient environments and contribute to soil fertility.

In the latter part of the 1970s, Prosopis juliflora was introduced to Ethiopia as a component of the green initiative, a reforestation effort aimed at tackling land degradation problems. This information is supported by studies conducted by (Mehari, 2015 and Birhane et al., 2017). Since its introduction to the Middle Awash areas of Ethiopia, it has overrun a huge hectare of grass and grazing lands which are mainstay for Afar pastoralists, including the study area District Awash Fentale (AF)(Mehari, 2015). Because, it has the ability to propagate across significant distances from where it was introduced.

According to Richardson et al., 2000, alien species can be categorized as casual, naturalized, or invasive based on their position within the naturalization-invasion continuum. As per the findings of Tadros et al., 2020, the annual rate of Prosopis juliflora invasion in Ethiopia was estimated to be around 31,127 hectares. After becoming established in its new habitat, this specific species consistently expands in pastoral regions, surpassing native flora and becoming the dominant vegetation in the Afar regional state of Ethiopia (Shiferaw et al., 2019 and Ravhuhali et al., 2021).

While Prosopis juliflora has economic importance, such as providing construction materials, fodder for animals, high-quality firewood, and charcoal (Oduor and Githiomi, 2013, Abdulahi et al., 2017, and Ravhuhali et al., 2021) in case of unmanaged growth can lead to the formation of dense impenetrable thickets, causing disturbances and erosion in grazing lands. Moreover, it has been identified as a major threat to biodiversity and the economic well-being of the people in Ethiopia.

The invasion of Prosopis juliflora in the Afar region was made easier by poor management techniques, societal conflicts over grazing lands, and local development measures that prevented its incursion into rangelands (Shiferaw, 2018).Without proper management practices in place, the spread of Prosopis juliflora becomes difficult to control and contain. Social conflicts over grazing areas have also contributed to the invasion of Prosopis juliflora. These conflicts may arise due to competing demands for limited resources, such as grazing areas for livestock.

For effective management and control of the invasive Prosopis juliflora plant, it is crucial to accurately ascertain and consistently monitor its spatial distribution. This information is vital for enhancing and prioritizing management strategies and initiatives (Shackleton et al., 2015). Furthermore, the presence of comprehensive spatial data on the invasion dynamics of Prosopis juliflora in the Afar region of Ethiopia, particularly in Awash Fentale District, is expected to greatly enhance the effectiveness and success of control and monitoring methods. According to a study conducted by Degefu et al. (2022), it was found that the rate of expansion of Prosopis juliflora in the District is significant, as all five kebeles within the District have been invaded. To tackle the problem of this invasive species in the study area, remote sensing methods using Google earth engine platform were utilized in this research to examine the spatial and temporal patterns.

Multispectral remote sensing utilizes multiple bands within the shortest bandwidth to accurately capture vegetation characteristics (Kumar, 2022). Spectral characteristics, which involve analyzing the reflectance of different wavelengths of light, can help identify and map the presence and distribution of invasive species. Temporal characteristics, which involve monitoring changes in vegetation over time, can reveal the spread and impacts of this invasive species.

Thus, the purpose of this study is to explore the spatial distribution of Prosopis juliflora using Sentinel-2 and Landsat pictures during the last thirty years (1993 to 2023) and examine how it affects local communities' means of subsistence. The researcher intended to prioritize the selection of Awash Fentale (AF) District as the study area because it possessed significant agricultural potential and was affected by the adverse consequences of Prosopis juliflora expansion into vast grazing land areas. Additionally, the District's density of population in comparison to other Districts in the area made it even more significant as a study topic. With access to detailed spatial information, authorities and researchers will be better equipped to understand the extent of the invasion, identify areas of high infestation, and develop targeted strategies for control and management.

1.2. Statement of the Problem

Recognized as one of the world's most invasive alien plant species, Prosopis juliflora has caused extensive harm to many of the Earth's dry ecosystems. Its encroachment into diverse land uses, including woodlands, grazing lands, parklands, urban green spaces, and farmlands, has significantly reduced the ecosystem services provided by these areas.

Although Prosopis juliflora has both positive and negative impacts on ecosystems, livelihoods, and socio-economic systems in arid and semi-arid areas, research by Degefu et al. (2022) indicates that local communities, including pastoralists and agro-pastoralists, believe the negative impacts outweigh the positive ones. According to Degefu et al. (2022), Prosopis juliflora has severely affected biodiversity and ecosystem services, rapidly spreading across rangelands in the study area and significantly reducing native plant species. Many key native trees and plants mentioned previously in the study have noticeably declined (Degefu et al., 2022).

Additionally, Prosopis juliflora has obstructed surface water sources, hindered the movement and management of irrigation water, encroached on flood protection dikes, and complicated the maintenance of irrigation canals and flood control structures. In Ethiopia, particularly in the Awash Fentale District, invasive alien species pose significant threats to biodiversity, agricultural lands, rangelands, protected areas, water bodies, and infrastructure, presenting both economic and ecological challenges (Alemayehu, 2006; Berhanu and Tesfaye, 2006; Dubale, 2008; Girma et al., 2011; Wakie et al., 2014).

Furthermore, information on the expansion of Prosopis juliflora is limited, and attempts to map its distribution in Ethiopia are sparse due to resource constraints (Witt, 2010; Akasaka, 2012; Wakie et al., 2014). Ground surveys and mapping activities to analyze Prosopis juliflora invasion rates are time-consuming and costly (Wakie et al., 2014). However, geospatial techniques offer valuable methods for mapping the distribution of invasive alien species (IAS), assessing their rate of infestation, and examining patch dynamics (Zeila, 2011). In this context, geospatial techniques provide useful approaches to analyze the spatio-temporal trends and behavior of IAS.

Although these techniques are critical for mapping historical invasion patterns at a district scale and over extended temporal contexts, such as thirty years, few studies have been conducted in Ethiopia's Afar region (Wakie et al., 2014). Additionally, there is a lack of quantitative assessments of Prosopis juliflora distribution in relation to spatio-temporal contexts.

Thus, studying the spatio-temporal trends of Prosopis juliflora, including its expansion patterns, responses to environmental factors, and relationships with climatic variables such as rainfall and temperature, will provide stakeholders with important information for targeted interventions. This study was conducted based on these considerations.

Despite extensive research efforts to identify suitable habitats for Prosopis juliflora across diverse geographic regions (Ng et al., 2018) and under various future climatic scenarios (Heshmati et al., 2019), our understanding of the current distribution and dominance of Prosopis juliflora remains insufficient in many regions, particularly in Ethiopia and, specifically, in the Afar region’s Awash Fentale District.

Fortunately, advancements in remote sensing techniques, such as land use and cover classification and vegetation indices, offer promising avenues to address this knowledge gap. The unique spectral properties of vegetation in the red and infrared portions of the electromagnetic spectrum (Xue and Su, 2017) allow for the identification and differentiation of various vegetation types across spatial and temporal scales. Using these advanced tools, this study employs remote sensing techniques to precisely map the spatio-temporal trends of Prosopis juliflora, examining the factors driving its distribution and assessing the resulting impacts on the residents of the Awash Fentale District. This research aims to contribute essential insights for immediate protective measures and the conservation of landscapes minimally affected by invasive Prosopis juliflora.

1.3. Objectives

1.3.1. General Objective of the study

The primary goal of this study is to investigate the spatio-temporal trends of Prosopis juliflora plantation and assess its overall impact on the livelihoods of rural communities in the Awash Fentale District, Afar region, Ethiopia.

1.3.2. Specific objectives of the study

The specific objectives of this study are to:

- Conduct a detailed analysis of the spatio-temporal trends of Prosopis juliflora plantation in the Awash Fentale District over a 30-year period (1993 to 2023).
- Assess the specific economic and social impacts of Prosopis juliflora plantation on the livelihoods of local communities within the study area.
- Investigate the influence of climate variability on the spatial expansion and growth dynamics of Prosopis juliflora in the Awash Fentale District.

1.4.Research Questions

Based on the specific objectives of this study, the following research questions were formulated:

1. What is the trend of Prosopis juliflora plantation in the Awash Fentale District from 1993 to 2023?
2. What are the impacts of Prosopis juliflora plantation on the economic and social well-being of local communities?

3. How does variation in climatic conditions influence the spatial and temporal expansion of Prosopis juliflora in the Awash Fentale District?

1.5. Significance of the study

Researching the Spatio-temporal trends of Prosopis juliflora plantation in the Awash Fentale District of Ethiopia's Afar Regional State, particularly through the use of Landsat and Sentinel-2 imagery on the Google Earth Engine platform, has multifaceted significance. This study provides critical insights into the expansion and impact of Prosopis juliflora on local landscapes and livelihoods. Leveraging advanced geospatial technologies enables high-resolution Spatio-temporal analyses, facilitating the identification and monitoring of changes in vegetation cover, land use, and ecological dynamics over time. Such insights are vital for land managers and policymakers aiming to mitigate the adverse effects of invasive species and promote sustainable land use practices. The creation of accurate, up-to-date maps of vegetation distribution and change directly supports efforts to manage and restore ecosystems affected by this invasive species.

The study contributes to the academic understanding of invasive species dynamics in semi-arid environments. By integrating ecological invasion theory with geospatial analysis, this research offers a novel approach to studying invasive species and their interactions with socio-economic and environmental systems. The methodological integration of remote sensing data with geospatial tools also serves as a case study for leveraging emerging technologies in ecological and environmental research. The findings will enrich the body of knowledge in invasion biology, land use change analysis, and socio-ecological resilience.

This research exemplifies the application of cutting-edge remote sensing technologies and platforms, such as Google Earth Engine, in addressing complex environmental challenges. The use of multi-temporal Landsat and Sentinel-2 imagery provides a robust framework for monitoring long-term ecological changes. Additionally, the study's integration of spatio-temporal analyses with socio-economic assessments serves as a methodological blueprint for interdisciplinary research, demonstrating how data from diverse sources can be synthesized to yield actionable insights. The methodological approach also highlights the importance of accuracy assessment and validation in geospatial studies, contributing to best practices in remote sensing research.

1.6. Scope of the study

This study will examine the spatio-temporal trends of Prosopis juliflora vegetation, focusing on how rainfall and temperature variability influence its density and distribution. Additionally, the study will explore the impact of Prosopis juliflora invasion on the economic and social welfare of local communities in the research area. This includes investigating how the spread of this invasive species affects the livelihoods, resource access, and traditional lifestyles of people in the Awash Fentale District.

The analysis will address various aspects of livelihoods impacted by the presence and spread of Prosopis juliflora, such as livestock breeding, agriculture, and natural resource development. It will also assess the potential benefits and challenges that Prosopis juliflora may present for these livelihood activities.

The study focuses specifically on the Awash Fentale District within the Awash River Basin in the Afar regional state of Ethiopia, covering the period from 1993 to 2023. In addition to enhancing understanding of the spatio-temporal trends of Prosopis juliflora plantation and its effects on local livelihoods, this research aims to offer a comprehensive analysis of satellite remote sensing applications to study vegetation response to climatic variability.

1.7. Limitations of the study

This study's limitations primarily stem from its specific focus on the Awash Fentale District and the time frame of 1993 to 2023 for examining the spatio-temporal trends of Prosopis juliflora plantation and its effects on local livelihoods using Sentinel-2 and Landsat data. While this approach offers valuable insights into Prosopis juliflora dynamics within this district over a thirty-year period, it is important to recognize that the results may not be directly applicable to other districts or regions beyond Awash Fentale.

Moreover, the trends observed within this period may not fully capture long-term or future patterns of Prosopis juliflora plantation, necessitating caution when generalizing findings outside the specific context of the Awash Fentale District and this selected period. This limitation highlights the need to account for potential variations and shifts in Prosopis juliflora dynamics across different regions and over longer timescales when interpreting and applying the study’s conclusions.

1.8.The format of the thesis and the outlines of its chapters

The research project comprises five chapters. The initial chapter serves as an introduction to the study. In the second chapter, the related concepts and empirical literature are discussed. The third chapter presents a description of the study area and research methodology. Chapter four focuses on the presentation of the study's results and subsequent discussion. Finally, the fifth chapter concludes the research and provides recommendations.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1.A brief account of invasive alien plants

This literature review seeks to examine the current understanding and studies concerning the spatiotemporal patterns of Prosopis juliflora plantations and their effects on local livelihoods. The introduction of Prosopis juliflora globally was largely influenced by environmental challenges such as deforestation, desertification, and scarcity of fuelwood, which became critical issues during the late 1970s and early 1980s. To combat these challenges, various initiatives were undertaken to introduce resilient tree species, including Prosopis juliflora, in many parts of the world (Masakha and Wegulo, 2015). The species was seen as a potential solution to these pressing problems due to its adaptability to arid and semi-arid conditions and its ability to provide essential goods and services such as firewood, fodder, and shade.

In Ethiopia, particularly in the Afar region, Prosopis juliflora was introduced during the late 1970s and 1980s. This introduction was spearheaded by foreign individuals working in the Middle Awash area. The primary purpose of introducing Prosopis juliflora was to use it as a windbreak, provide shade, and create shelter in the region's challenging climatic conditions. However, these introductions were not accompanied by comprehensive knowledge or understanding of the plant's ecological and socio-economic impacts, as noted by Tessema (2012) and Berhanu et al. (2006). Consequently, while the plant offered initial benefits, its long-term effects on the environment and local communities were not anticipated.

Prosopis juliflora, like many invasive alien species, presents a complex duality. Humans have widely accepted numerous non-native species for their roles in supporting local livelihoods and national economies. For instance, Shackleton et al. (2007) highlight that non-native species, including Prosopis juliflora, can provide valuable goods and services, such as timber, fodder, and soil stabilization, which are essential for both subsistence and commercial purposes. However, the introduction of such species often carries unintended consequences. In the case of Prosopis juliflora, its invasive nature has led to significant ecological changes, including the displacement of native vegetation, alterations in soil composition, and the disruption of local ecosystems.

Moreover, the socio-economic impacts of Prosopis juliflora have been a subject of considerable debate. While the plant has contributed to some aspects of rural livelihoods, such as providing firewood and fodder during dry seasons, it has also created challenges for local communities. For example, its aggressive spread has reduced grazing lands, leading to conflicts among pastoralists and farmers. According to Berhanu et al. (2006), the dense thickets formed by Prosopis juliflora have hindered access to water sources and fertile lands, exacerbating livelihood vulnerabilities in affected areas.

The spatiotemporal patterns of Prosopis juliflora's spread are closely linked to both natural and anthropogenic factors. Climate variability, soil type, and water availability significantly influence its distribution, while human activities such as land use changes and livestock movement further facilitate its expansion. Studies by Tessema (2012) emphasize that the plant's proliferation in the Afar region has been exacerbated by poor management practices and a lack of coordinated efforts to control its spread. These patterns highlight the importance of adopting an integrated approach to managing invasive species, combining ecological understanding with socio-economic considerations.

In conclusion, the introduction and spread of Prosopis juliflora in Ethiopia exemplify the complex interplay between ecological resilience and socio-economic dynamics. While initially introduced to address environmental challenges, the plant's invasive nature has led to unforeseen consequences that impact both ecosystems and livelihoods. As the spatiotemporal dynamics of Prosopis juliflora continue to evolve, there is a need for comprehensive studies and coordinated management strategies to mitigate its negative effects while harnessing its potential benefits.

2.2 The geographic spread of Prosopis juliflora

Prosopis juliflora , a plant species native to North America (specifically Mexico) and Central America (including Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama), has spread swiftly and become naturalized in numerous tropical and subtropical regions across the globe (Dakhil et al., 2021). Its invasive nature in these regions is a cause for concern due to its alarming rate of expansion.

In Ethiopia, the diverse ecosystem of the country is home to both native and non-native species, influenced by natural conditions (EBI, 2014). From the 1980s onwards, there has been a rapid expansion of the plant in the eastern regions of Ethiopia, extending from the Middle Awash Valley to the Upper Awash Valley, Eastern Hararghe, Dire Dawa, and certain areas of the Raya Azebo plains in South Tigray (Wakshum Shiferaw et al., 2018). The encroachment of the plant has also been documented in the town of Arba Minch, South Omo, and adjacent areas in the southern part of the country (Shetie Gatew, 2008; Wakshum Shiferaw et al., 2018). This invasion has prompted the need for research and investigation into the impacts and management of this plant species.

2.1.Ecological consequences and interactions

An alien plant species is classified as invasive when it surpasses its natural range of distribution, resulting in damaging effects on the environment, individuals, economy, or human well-being (Richardson et al., 2003). The introduction of alien species through biological invasions is currently recognized as a noteworthy contributor to the global decline in biodiversity and the listing of endangered species. Furthermore, the invasive nature of Prosopis juliflora species can lead to damaging effects on ecosystem services, water supply, grazing availability, native biodiversity, and local economies. (DeLoach, (1984), Bedunah and Sosebee (1986). Invasive species have significant ecological, economic, and social repercussions and play a pivotal role in driving global change (Shackleton et al., 2014). So, the encroachment of Prosopis juliflora in various regions of Africa has emerged as a primary factor causing adverse consequences for the structure and functioning of local communities, resulting in heightened vulnerability (Shackleton, 2024).

In areas where Prosopis juliflora has established itself, it hinders the growth of grasses beneath its canopy, leading to a decline in biodiversity (Niguse and Amare, 2016). The spread of Prosopis juliflora has significant socio-economic implications for local communities. According to the research conducted by Shiferaw et al. (2022), there was a significant invasion of Prosopis juliflora species in rangelands, resulting in a direct negative impact on livestock production and productivity. This invasion poses a threat to agro-pastoral livelihoods. The species of Prosopis juliflora is found as an invasive weed which has numerous adverse effects on social, ecological, and economic aspects (Shackleton et al., 2014), in many regions globally, particularly in dry and semi-arid environments. Multiple studies have shown that the invasion of Prosopis juliflora is responsible for biodiversity loss in various regions across the globe (Schachtschneider and

February, 2013). The areas of the Awash Fentale District, being located in the Afar Regional State, has been among the greatly affected districts by the spread of the invasive alien Prosopis juliflora plant (IAPP).

The rapid expansion rates, capacity for regrowth through coppicing following damage, and extensive and intricate root systems contribute to the effectiveness of Prosopis juliflora as an invasive species in dry and semi-arid regions. The plant demonstrates adaptability to extreme climatic conditions characterized by high temperatures and limited rainfall, thriving even in nutrient-deficient soils (Shiferaw et al., 2004). According to Sivakumar et al. (2018), Prosopis juliflora is the sole non-native species with the ability to thrive in diverse soil types and climatic conditions. Prosopis juliflora exhibits satisfactory growth without the need for modifications in soil conditions, even in environments with a pH of up to 9 (Sivakumar et al. 2018). The species possesses invasive traits, enabling its growth across diverse ecological zones and adaptability to a extensive range of soil types, including sandy, clayey, saline, and alkaline soils. It is capable of thriving at altitudes ranging from below 200 meters to above 1500 meters above sea level, and in areas experiencing mean annual rainfall between 50 mm and 1500 mm (Shiferaw et al., 2004).

In certain nations, such as Ethiopia, specific attributes of the pastoral livelihood systems observed in arid and semi-arid areas can potentially facilitate the rapid proliferation of Prosopis juliflora (Shiferaw et al., 2004). This phenomenon occurs because the majority of livestock, including goats, camels, donkeys, and cattle, consume the seed pods of Prosopis, especially when the region experiences dry seasons and droughts, resulting in limited availability of grazing land. As pastoralists move across various locations in search of pasture and water for their livestock during these challenging times, they inadvertently introduce and disperse Prosopis juliflora into new areas (Wakie et al.,2016). Despite Prosopis juliflora's substantial ecological and socioeconomic effects, there aren't many reliable methods for assessing its geographic range.

2.2. Study of the biological aspects of Prosopis juliflora

Prosopis juliflora , a species known for its tolerance to saline conditions, thrives in the vicinity of water sources such as water holes and river tributaries found at lower altitudes within the Great Rift Valley of Ethiopia (Shiferaw et al., 2018). The species possesses various biological traits that facilitate its swift colonization of unfamiliar territories (Hailu et al., 2004).This versatile plant is currently extensively cultivated in tropical regions, serving multiple purposes including providing shade, timber, and forage (Samuel Getachew et al., 2012, and Sivakumar et al. 2018).

Prosopis juliflora typically occurs in regions where water scarcity and inadequate soil fertility are the main factors restricting plant development. It can endure and even thrive in some of the most infertile land, which is unsuitable for other tree species (Pasiecznik et al., 2001). Prosopis juliflora can be found in various habitats such as grasslands, shrublands, and arid forests. This species exhibits remarkable tolerance to both salt and drought conditions. Additionally, it possesses the ability to fix nitrogen, has deep-rooting capabilities, and can thrive in dry soil environments. As it grows, the tree quickly establishes dense thickets with thorns, which unfortunately leads to a reduction in the diversity of native species and impacts wildlife habitats.

2.5 Climate Change and the Expansion of Invasive Species

Climate change is an inherent phenomenon linked to the evolution of our planet. Two significant factors contributing to the decline of biodiversity in the present era are climate change and the spread of invasive species (Mainka, 2010). The distribution, reproductive practices, and behavior of different species are already being impacted by the consequences of climate change. Furthermore, all available evidence indicates that even with immediate action to mitigate greenhouse gas emissions, the situation is likely to worsen. We can expect rising temperatures, altered precipitation patterns, sea-level rise, and changes in ocean chemistry.

Simultaneously, the introduction and establishment of invasive species continue to pose a significant threat to biodiversity. This threat results in the loss of species, shifts in their geographical distribution, and degradation of natural habitats(Mainka, 2010). It is crucial to address both climate change and invasive species to safeguard biodiversity and promote ecological resilience. The effects of climate change on different species are not uniform, varying both in terms of taxonomy and geographic location. Foden et al. (2008) proposed a list of traits that could make a species more vulnerable to the impacts of climate change. These characteristics include species that exhibit unique habitat and/or microhabitat preferences, which may limit their adaptability to changing conditions. Additionally, species with a limited ability to tolerate or withstand environmental changes that may occur due to climate change during any phase of their life cycle are at greater risk.

Moreover, reliance on specific environmental stimuli or signals that could be disrupted by climate change further increases vulnerability. Species that depend on interactions with other species, which may also be disturbed by climate change, face additional challenges. Finally, the negative impacts of climate change are most likely to affect individuals who have limited ability or limited opportunity to migrate or establish in a new or more suitable geographic range.

Invasive species have the potential to result in the decline of biodiversity, modifications in water chemistry, disruptions to biogeochemical processes, alterations to hydrological systems, and changes to food webs (Ehrenfeld 2003; Dukes & Mooney 2004). Additionally, they can bring about transformations in ecosystems and ecological dynamics.

These changes in the natural environment create openings for other unfavorable occurrences to take place. Among these is the introduction of non-native species, whether intentional or unintentional, during disturbances to ecosystems. Non-native species' introduction has a variety of effects, such as displacing native species, upsetting the ecological balance, harming fishing and farming methods, and preventing socioeconomic growth.

2.6. Possible advantages of Prosopis juliflora

2.6.1. Economic benefits of Prosopis juliflora

The introduction of plant and animal reproductive parts from outside their native habitats has contributed to the enhancement of human well-being. Global trade, as one of the pathways for invasive species, has played a significant role in facilitating the movement and establishment of species worldwide, allowing modern societies to reap unprecedented benefits (McNeely et al., 2001). The wood derived from Prosopis juliflora serves multiple purposes, including as a source of fuelwood or structural material. In its capacity as fuel, it can be directly burned or transformed into charcoal. Additionally, the timber can be utilized as poles or crafted into furniture (Mwangi and Swallow, 2005). For over 5000 years in their original habitats, Prosopis juliflora species have been utilized for a diverse range of products (Pasiecznik et al., 2001). Within its invasive distribution areas, Prosopis juliflora is widely used for a variety of functions, including fuel, fodder, windbreaks, shade, construction materials, and soil stabilization, according to a 2001 study by Pasiecznik et al. in Africa and Asia. On the other hand, Prosopis juliflora was used more for medical purposes than for fodder, fuelwood, and shade (Shackleton et al., 2015). For many households, the advantages derived from Prosopis juliflora were, or are, considered a significant source of income in certain areas, which is true to this particular study area Awash Fentale District.

According to study by Shiferaw et al (2022) in Awash Fentale of Afar regional state, the main reasons considered for the introduction of Prosopis juliflora were fuelwood, shade, soil and water conservation purpose of the plant. Numerous researchers have extensively discussed the spatio-temporal patterns and livelihood impacts of the Prosopis juliflora plant species across different geographical regions of the world. These studies have highlighted both the benefits and negative consequences associated with Prosopis juliflora plants' invasive nature of expansion.

2.6.2. The ecological advantages of Prosopis juliflora

Prevention of soil erosion

The most valuable component of the soil layer is the humus found in the topsoil, which requires significant time to form. Essential nutrients for plants and helpful microbes are abundant in the topsoil. However, it is susceptible to erosion caused by water and wind. In numerous semi-arid regions, a barrier of Prosopis juliflora is strategically planted around fields to diminish the velocity of wind.

Soil fertility management and rehabilitation

The introduction of unfamiliar species modifies the nutrient dynamics by changing the physical attributes of the soil (Boettcher and Kalisz, 1989). When unfamiliar species are introduced into an ecosystem, they can have a significant impact on the nutrient dynamics within the soil. This occurs through the alteration of the physical attributes of the soil itself. These alien species may alter the soil's structure and composition, which may impact the soil's capacity to hold and release nutrients. Prosopis juliflora has a beneficial impact on the physico-chemical characteristics of soil in diverse ecosystems, including deserts, shrublands, and agroforestry systems (Schade and Hobbie, 2005; Wick and Tiessen, 2008). The development of plants and the general operation of ecosystems may be impacted by variations in nutrient dynamics.

2.7. The negative impacts of Prosopis juliflora

The presence of invasive non-native plants has been linked to the decline of endangered and vulnerable species. These plants have the ability to disrupt ecosystem processes, modify the structure of vegetation, and replace native species. This is often due to their ability to establish high densities and biomass (Surendra et al., 2013). According to Yibekal Abebe (2012), Prosopis juliflora poses a threat to the native plant species in the Afar region of Ethiopia, including Acacia prasinata, Boswellia ogadensis, Euphorbia doeloensis, Euphorbia ogadensis, and Indigofera kelleri. These habitats not only support endangered plant species but also provide a home for numerous globally threatened and vulnerable mammal and bird species.

The integrity of the ecosystem in the Afar region is being compromised, leading to further endangerment of wildlife. A study by Abyot Berhanu and Getachew Tesfaye (2006) revealed that Prosopis juliflora has replaced the local biodiversity in various locations within the Afar region, particularly in rangelands and dry riversides. Consequently, the ecological function has changed from rangeland to dense Prosopis thickets, and the grasslands in these places are no longer suited for grazing. As a result, the indigenous pastoralists in the Afar region of Ethiopia were forced to relocate farther away from their homes and grazing lands, exacerbating the scarcity of food and fodder.

Research conducted by Mitiku S.G. (2008) in the Amibara District of the Afar region in Ethiopia revealed that Prosopis juliflora has significantly encroached upon dense Acacia woodlands, riverine forests, and agricultural lands. This concept is generally valid for the nearby District Awash Fentale, despite the fact that no comparable study has been conducted as of yet.

2.8. Methods for monitoring the spatial and temporal dynamics of Prosopis juliflora

To regulate and manage the invasive Prosopis juliflora, accurate and consistent monitoring of its spatial distribution is essential (Shackleton et al., 2015). Researchers have used various methods to assess its temporal and spatial dispersion, with remote sensing proving to be a reliable technique (Broich et al., 2011). For instance, Rembold (2015) used Landsat imagery to map Prosopis invasion in Somaliland, while Assefa et al. (2023) employed Sentinel-2 data and GIS technologies to analyze its spatial extent during dry seasons. Shiferaw et al. (2019) utilized NDVI to map its distribution, highlighting its ability to capture vegetation photosynthesis and moisture content. Similarly, Sisay (2021) analyzed spatial and temporal trends in Ethiopia’s Afar region. Although advancements such as Sentinel data, radar, and machine learning algorithms offer promising solutions (Santoro et al., 2018; Liu, 2022), challenges in change detection remain significant (Coppin and Bauer, 1996).

2.9. Remote Sensing Technology for Spatio-temporal vegetation trend analysis

Remote sensing technology involves the use of satellite imagery, aerial photography, and sensors to collect data about the Earth's surface without direct contact, enabling efficient mapping of rugged terrains (Biswas et al., 2020; Liu et al., 2018). It is extensively applied in forest analysis due to its accuracy and ability to integrate optical, radar, GIS, and climate data for comprehensive environmental insights. This integration provides critical understanding of geographical phenomena and enhances environmental research.

2.9.1. Image Acquisition and sources

Image acquisition involves capturing images using remote sensing technologies that detect electromagnetic radiation from the Earth's surface. These images are acquired via satellite sensors, aerial photography, or ground-based instruments, categorized into passive and active sensing systems. Passive remote sensing, such as Landsat MSS and SPOT Push Broom Scanners, measures reflected sunlight, while active systems emit radiation and measure its reflection back. For vegetation studies, optical data, particularly in the near-infrared (NIR) spectrum, is widely used to assess plant health, evapotranspiration, and forest types (Shimizu, Ota, & Mizoue, 2019; Verbyla, 1995; Rees, 2013).

Freely available satellite data, such as Landsat and Sentinel, play a crucial role in spatial analysis. Since 1972, NASA and USGS's Landsat missions have provided data for vegetation mapping. Recent models, Landsat 7 and 8, include advanced sensors like ETM+ and OLI, enabling detailed seasonal monitoring of vegetation and land use (Xie, Sha, & Yu, 2008; Zhu et al., 2019). Surface reflectance products from Landsat enhance change detection by addressing atmospheric factors and integrating auxiliary data inputs, utilizing algorithms like LaSRC and LEDAPS (Vermote et al., 2016; Masek et al., 2006).

Sentinel, part of ESA's Copernicus Programme, offers high-resolution multispectral data via Sentinel-2A and 2B, which revisit locations every five days and provide 10-meter resolution imagery. These sensors are crucial for creating natural color images and vegetation maps using NIR and red bands, contributing to comprehensive Earth monitoring (Carrasco et al., 2019; ESA, 2019). Recent advancements in remote sensing integrate radar, multispectral data, and GIS, offering deeper insights into environmental and geographical phenomena.

Table 2. 1: Summary of freely available Open-source data

Satellite name	Data source	Missions	Spatial resolution	Launched in
Landsat	USGS Earth Explorer	Landsat 1-8	30m	1972
Sentinel	European Space Agency	Sentinel 1-6	10m-60m	2014
MODIS	NASA	Terra and Aqua	250m	1999
NOAA-AVHRR	USGS	NOAA 6-14	1.1km	1979
GEDI	International Space Station	GED	I km	2019
BIOMASS P-band SAR satellite	European Space Agency	Biomass	60m	2023
SRTM	NASA	SRTM GLI	30m	2000

Source: Walawe Durage, (2023).

Thus, this research utilized two publicly available, remotely captured data sets: (1) different versions of the Landsat imageries including Landsat 5 Thematic Mapper(TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Operational Land Imagery (OLI), and (2) the sentinel 2 imageries.

2.10. Application of the google earth engine in mapping spatial and temporal distributions of vegetation change

Due to progress in data sources, software, and image analysis methods, remote sensing has emerged as a cost-effective approach for forest classification. Nonetheless, developing countries have faced constraints in accessing this technology due to the expensive nature of high-resolution images and analysis software. A possible remedy to this issue is the provision of free access to mid-low resolution satellite images by NASA and the European Space Agency.

Additionally, Google Earth Engine (GEE), a user-friendly cloud-based platform for geospatial research, was introduced in 2010. According to Walawe Durage (2023), researchers from developing nations can now conduct investigations without the need for expensive remote sensing software because of its capacity to do large computations (Wu et al., 2018). Convenient online access to a sizable library of satellite images, including MODIS and Landsat data, covering almost four decades is provided by the Google Earth Engine (GEE) platform. Moreover, it provides advanced tools that enable "trusted testers" to explore this extensive image archive, detecting changes, mapping trends, and quantifying differences on the Earth's surface (Hird,2017).One notable benefit of GEE is that it eliminates the requirement for high-performance computers with significant processing capabilities and substantial storage capacities.

The Application Program Interface (API) of the Google Earth Engine (GEE) facilitates the retrieval, creation, and utilization of algorithms on the comprehensive Earth Engine data repository through Google's cloud computing and processing platform (Erickson, 2014 and Hancher, 2013). Simonetti et al. (2015) devised a completely automated classification algorithm using the GEE to generate land-cover maps in Sub-Saharan Africa, incorporating phenology information based on time-series data from Landsat-8 OLI imagery. The Google Earth Engine (GEE) Application Program Interface (API) enables users to access, develop, and apply algorithms on the extensive Earth Engine data archive using Google's cloud computing and processing platform.

2.10.1. The application of Google earth engine in image classification

Google Earth Engine (GEE), a cloud-based computing platform, offers a solution to the major challenges associated with mapping land cover in extensive regions. Without downloading the data to their local computers, users can evaluate a variety of remotely sensed photos using an online Integrated Development Environment (IDE) code editor (Phan et al., 2020). This allows for efficient and convenient land cover mapping of large areas using GEE's powerful capabilities.

Image classification can be carried out using either a pixel-based or object-based classification methodology (Camarretta et al., 2020). In pixel-based classification, the numerical foundation for categorization is established by utilizing the spectral pattern of individual pixels (Vick, 2008). On the other hand, object-based classification takes a different approach by grouping pixels into objects and classifying these objects based on various factors such as shape, size, color, spatial variation, and contextual information (neighboring data) (Crowley and Cardille, 2020).

2.10.2. Machine learning classification techniques and classifiers

Machine learning methods are increasingly effective for precise mapping due to the abundance of image data and the integration of multiple data sources (Walawe Durage, 2023). Despite requiring larger training datasets, these methods often surpass traditional classifiers in accuracy (Tsai et al., 2018). Supervised classification in remote sensing has advanced significantly with algorithms like SVM, CART, and Random Forest. The SVM algorithm, introduced by Vapnik in 1995, excels with limited training datasets by optimizing class separation (Lien, 2018; Jensen, 2016). CART, developed by Leo Breiman in 1984, and Random Forest are particularly impactful, with RF recognized as a leading approach for land cover classification (Johansen, 2015; Carrasco et al., 2019). RF's popularity stems from its robustness against outliers and noisy data (Mahdianpari et al., 2017; Xia et al., 2017).

Research on Prosopis juliflora has been conducted at national and local levels, especially in Ethiopia's Awash Basin and Afar region, due to its early introduction. These studies explore various impacts of the invasive species, focusing on socio-economic and ecological aspects. In the Awash Fentale District, research highlights the need for targeted management strategies. Further monitoring and localized studies can inform sustainable approaches to mitigate the invasion’s impacts on communities and ecosystems, addressing unique regional challenges.

2.11. Conceptual Framework of the Study

The conceptual framework for this study is a structured representation of the key variables, their interconnections, and the methodologies employed to explore the Spatio-temporal dynamics of Prosopis juliflora plantation and its impacts on livelihoods.

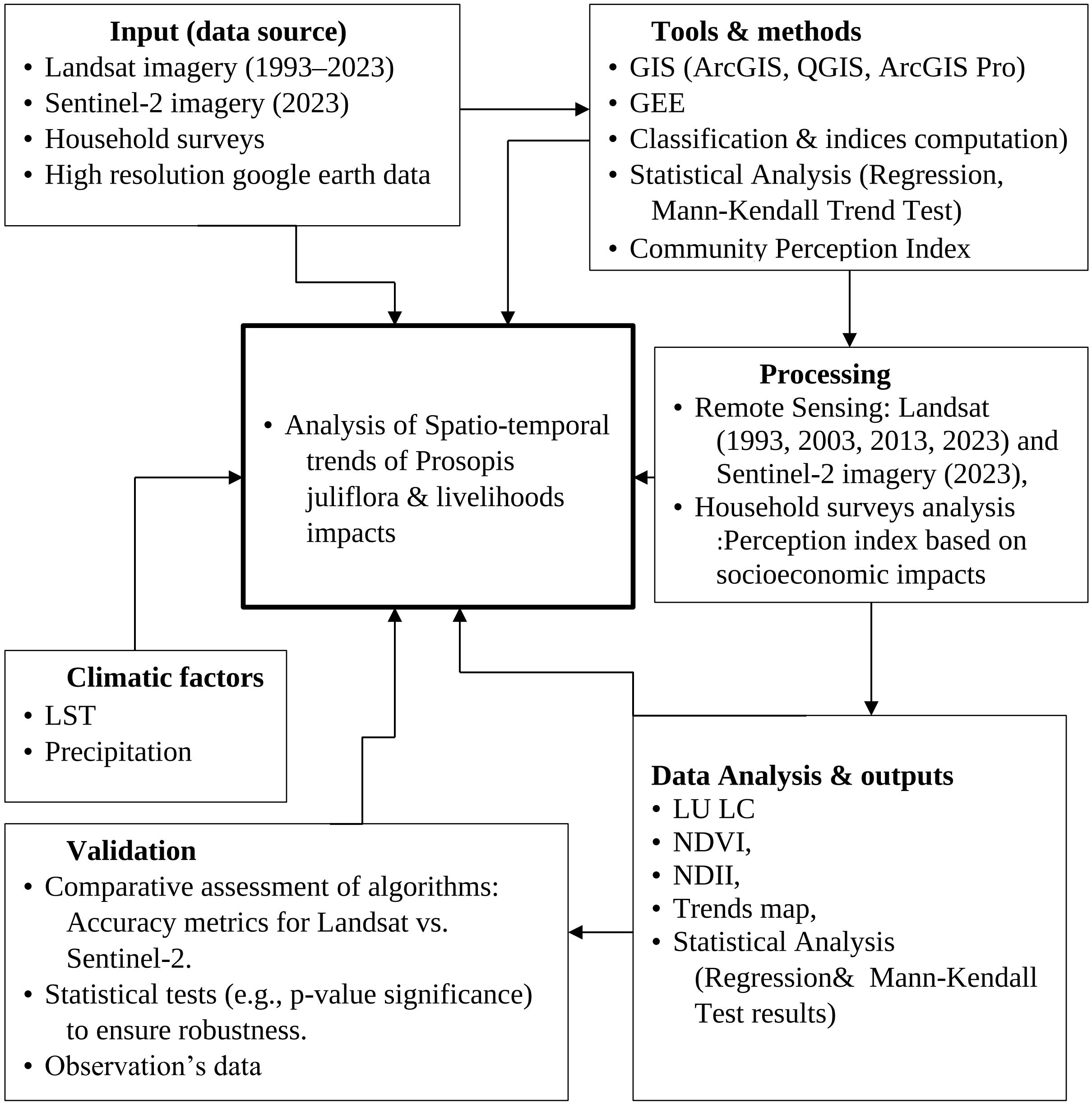


Figure 2 1: Conceptual frameworks (Source: own construction, 2024)

CHAPTER THREE

MATERIALS AND METHODS

3.1. Description of the study area

Awash Fentale Woreda is situated within Zone 3 of the Afar Regional State. It shares its borders with Dulecha to the north, Amibara Woreda to the east, Fentale to the west, Gumbi Bordede Woreda of the Oromia Region to the southeast, and Berehet Woreda of the Amhara Regional State to the northwest (Figure 3.1). Administratively, the woreda is divided into five rural kebeles: Kebena, Boloyita, Doho, Diduba, and Awash Beherawi Park, along with two towns, Sabure and Awash Sebat Kilo. This woreda is positioned at the base of the eastern mountains of the Amhara region, where the Kebena and Kesem rivers originate, traversing the area. The Kebena, Bulga, and Awash rivers, along with their tributary Germam, flow through the district. It covers an area of 105,788 hectares (ha). Altitudinally, the Awash Fentale District lies between 667 and 1,386 meters above sea level. Within the district, there is a noticeable variation in elevation. This places the district within the lowland agro-ecological zones of Ethiopia, making it a unique area within the country with these specific characteristics.

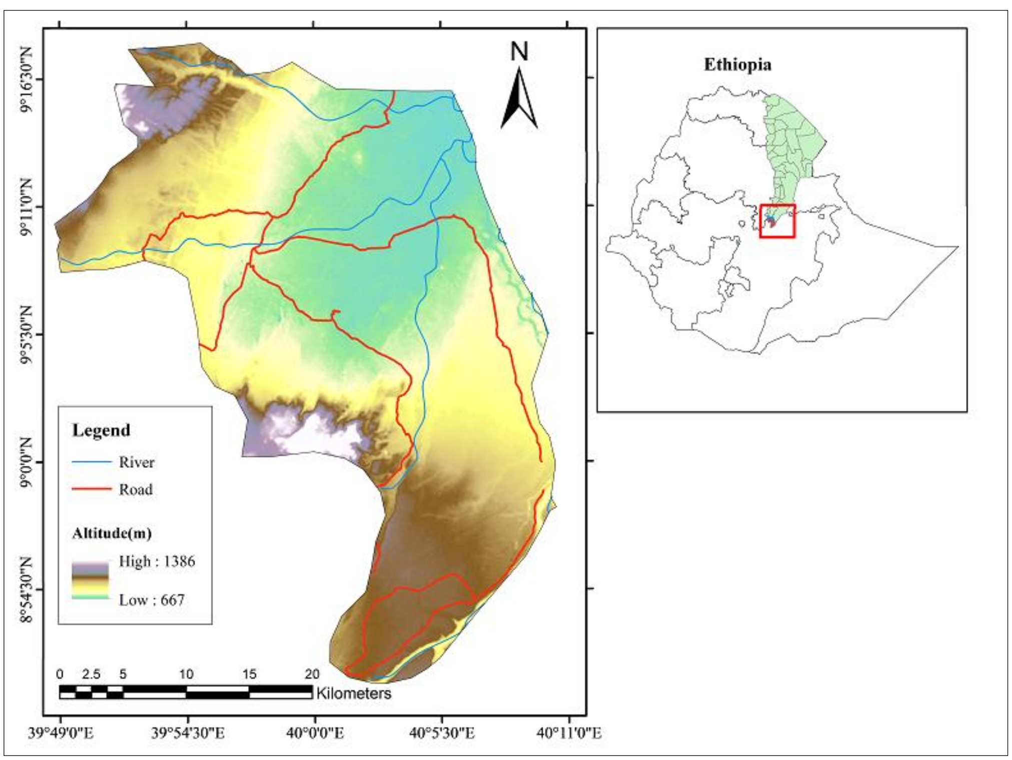


Figure 3. 1: Location map of the study area

3.2.Climate

The climatic conditions of the study area are expressed in terms of rainfall and temperature. Rainfall data were extracted from the TerraClimate dataset (ClimateEngine.org). In the study area climatic data is computed for time points that represent intervals of approximately 10 years, allowing for the identification of decadal patterns and trends in climate data as decadal spacing provides a balanced temporal framework to evaluate long-term climatic variations. The average annual rainfall for the four time points (1993, 2003, 2013, and 2023) is measured at 680 mm (Table 3.1), while the annual evapotranspiration ranges from 300 to 700 mm, as derived from the TerraClimate dataset (ClimateEngine.org).

Table 3. 1: Average precipitation values for the study area in 1993, 2003, 2013, and 2023

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1993	48.82	93.24	4.88	143.06	61.43	34.32	136.45	95.40	56.51	27.07	0.00	3.67	704.84
2003	10.23	16.80	43.02	66.40	6.78	85.80	158.50	93.03	70.28	3.71	2.00	25.25	581.79
2013	14.37	1.00	59.90	50.26	169.66	97.24	140.06	120.65	38.29	51.78	26.12	0.00	769.34
2023	18.82	1.75	116.99	102.22	65.97	27.34	109.04	89.16	38.60	70.91	26.67	0.10	667.57

The study area is categorized as having a hot to warm moist climate. The mean annual temperature in this region varies between 18.17 °C and 33.93 °C during the period from 1993 to 2023, with an overall average annual temperature of 26.1 °C, as illustrated in Figure 3.1.

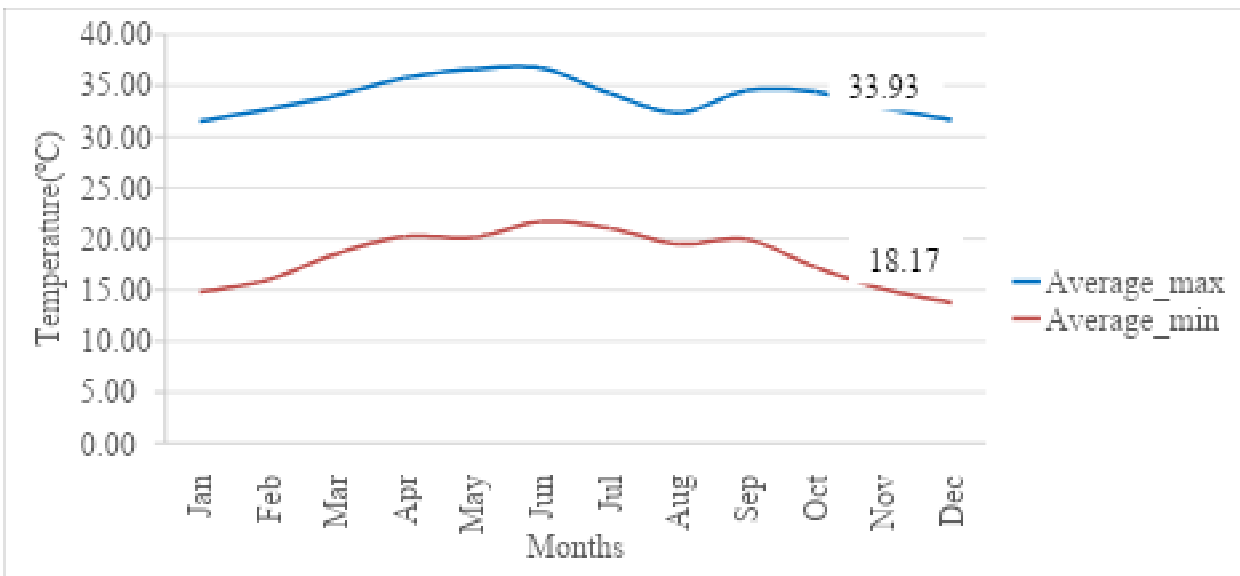


Figure 3. 2: Average maximum and minimum temperatures over three decades (1993–2023).

3.3.Vegetation

The landscape features grassland, open bushland, and forest along perennial river courses. However, the invasive species Prosopis juliflora have impacted large areas of native grasslands, shrublands, and woodlands (Bekele et al., 2018). Table 3.2 below displays the common vegetation types of the Awash Fentale District.

Table 3. 2 : Overview of common vegetation in the Awash Fentale District (Vernacular and Scientific Names)

Vernacular name	Scientific name
Adengali	Cadaba Rotundifolia
Kasalto	A.nilotica
Adalita	Acacia Senegal
E'ebto	A. tortilis
Adaito	Salvadorapersica
Gerento	A.oerfota
Gerssa	Dobera Glabra
Hedayto	Grewia Tenax
Mederto	CordiaSinensis
Ayti-adoyta	Terapogoncenchriformis
Delaita	Setaria Acromelaena
Halal	Ipomoea Sinensis
Irareyta	Cynodon Dactylon
Woyane zaf (Prosopis)	Prosopis juliflora (Sw.) DC.

Source : Mehari, (2015).

The plant species listed in Table 3.2 directly impact the livelihoods of local communities, particularly in agriculture, livestock grazing, and resource utilization. Alongside the native vegetation, the introduction of Prosopis juliflora has significantly affected the ecological balance in the district. While Prosopis juliflora thrives in arid conditions and provides shade and fodder, it is also criticized for its invasive nature. Its rapid spread can outcompete native plants for resources, resulting in a decline in biodiversity. This shift can alter the structure of the local ecosystem, impacting both the flora and fauna that rely on native species for habitat and food.

The Awash National Park (ANP), located in the Awash Fentale District, is recognized as one of Ethiopia's prominent conservation areas, renowned for its diverse wildlife and rural scenery (Tezera Chernet, 2015). The wildlife in ANP is characterized by a rich diversity of species, including various mammals, birds, and reptiles, all adapted to the park's unique ecosystems, which range from arid Acacia woodlands to riverine wetlands.

However, based on personal observations and key informant interviews (KII), the introduction and spread of Prosopis juliflora have posed less significant challenges to wildlife within the ANP compared to the surrounding areas. This is primarily due to restrictions on cattle and goat access to the park, which limit interactions between the internal wildlife and external populations. As a result, the mechanisms of dispersal within the park are not highly functional.

3.4. River

The Awash River and its tributary, the Germama, are vital to the Awash Fentale District. These rivers serve as essential water sources for both local communities and wildlife, particularly in an area characterized by arid and semi-arid climates. Conversations with local residents reveal that the Awash River and Germama support various agricultural irrigation schemes, enabling the cultivation of crops such as vegetables and cereals, which are crucial for local food security and livelihoods. The water provided by these rivers allows farmers to grow crops year-round, despite the typically dry conditions of the Afar region.

3.5.Livelihoods

The livelihoods of the pastoral community in the study area primarily rely on livestock production, including camels, cattle, goats, sheep, and donkeys. These animals are crucial for generating income, creating jobs, ensuring food security, and maintaining cultural identity. However, the encroachment of Prosopis juliflora on their rangelands has led to the loss of essential forage resources, significantly impacting the sustainability of livestock production.

While some respondents from Gobil Kebele have pointed out that this invasive species can be used as fodder, it has also caused various negative effects on local agriculture and pastoral practices. It reduced arable land by overtaking grazing areas and fertile agricultural land, thereby limiting the space available for traditional livestock grazing and crop cultivation. Consequently, the well-being of the pastoral community in the region has been severely affected.

3.6 Data Sources and Materials

In this study, multi-temporal imagery, specifically Landsat 5 TM, Landsat 7 ETM+, Landsat 8 OLI, and harmonized Sentinel-2 spanning from 1993 to 2023, was utilized to analyze the trends of Prosopis juliflora plantation over a 30-year period. As Landsat satellites provide continuous, consistent imagery from 1972 to the present. This long history makes Landsat the ideal choice for analyzing changes over a 30-year period, such as the spread of Prosopis juliflora. Additionally, Sentinel-2 data for the year 2023 were employed to facilitate a performance comparison with the corresponding Landsat data. Before conducting the classification, visual observations of the Prosopis juliflora species' distribution were made based on the tone and saturation of the red color in the False Color Composite (FCC) of both Landsat and Sentinel-2 imagery. To assess the impact of various climatic variables, MOD11A1 data for Land Surface Temperature (LST) and CHIRPS data for Precipitation were incorporated. Ancillary data, including ground observations and high-resolution imagery from Google Earth Pro, were also collected.

To process and analyze these datasets, Google Earth Engine (for land use and land cover, Normalized Difference Infrared Index (NDII), Spectral Reflectance curve, and NDVI computations), ArcGIS version 8, ArcGIS Pro version 3.0, and QGIS version 3.4 were utilized. These software tools were instrumental in organizing and visually presenting the spatial data. By employing this comprehensive methodology, the research aims to provide a holistic understanding of the trends and factors influencing the study area over the specified time period.

3.6.1 Satellite imagery

To ensure the accuracy and credibility of this study, Landsat surface reflectance images from different years were utilized. Specifically, images captured in 1993, 2003, 2013, and 2023 were used. The filter date for all these images was set to a five-month period, spanning from January to May. This time frame was chosen strategically to minimize the impact of seasonal variations on land cover classification. Additionally, it was assumed that the main crops had already been harvested, considering the early stage of the next crop cycle. Therefore, image collections were specifically considered from January to June. To achieve a clearer representation of land cover, a median composite of the dataset was created for all time points, with a cloud filter set to less than 10 percent.

The analysis considered various spectral bands, including red, green, blue, NIR, SWIR-1, and SWIR-2, obtained from the TM-5, 7 ETM+, and OLI-8 platforms. Google Earth Engine was utilized to perform land use and land cover (LULC) classification and to compute the Normalized Difference Vegetation Index (NDVI), specifically focusing on identifying the class that accurately represents Prosopis juliflora. Consequently, the analysis of the classified data, the thresholding of the NDVI, and the interpretation and mapping of the patterns facilitated the identification of the density and spatial distribution of Prosopis juliflora vegetation cover in the study area.

Table 3. 3 : Selected satellite scenes and sensor characteristics used for the study area

Data type	Landsat TM	Landsat ETM+	Landsat_8 OLI	Sentinel_2
Spectral resolution	7 bands	7 bands	11bands	12 bands
Spatial resolution of multispectral bands	30 m	30 m	30 m	10 m/20 m
Scene selection Date and purpose	LULC classification and NDVI :1993	LULC classification and NDVI :2003 and 2013	LULC classification and NDVI :1993	LULC classification and NDVI :2023

Source: Wang et al.,2017

3.6.2 Climatic variables

Precipitation is crucial for understanding the spatial and temporal expansion of Prosopis juliflora. In this study, rainfall data were collected using the Climate Hazards Group Infrared Precipitation with Station data (CHIRPS) for the months of December through April in the years 1993, 2003, 2013, and 2023. This timeframe aligns with the period used to obtain imagery necessary for computing the NDVI. To effectively assess the impact of rainfall on vegetation, a time lag of one month was incorporated, recognizing that the effects of rainfall typically manifest approximately one month after precipitation events (Adepoju et al., 2019).

We utilized the CHIRPS dataset, which combines satellite imagery with ground station information to provide a high-resolution representation (0.05° or 5.55 km spatial resolution) of precipitation patterns. By merging satellite imagery with ground station data, CHIRPS estimates precipitation levels worldwide (Katsanos et al., 2016). This comprehensive dataset is further enhanced by using ground station measurements to calibrate and validate the satellite estimates, ensuring the accuracy of the final product (Funk et al., 2015). Consequently, we clipped the CHIRPS dataset for the study area.

The study also utilized the MOD11A1 product in Google Earth Engine to derive land surface temperature (LST). The MOD11A1 dataset, widely employed for analyzing spatiotemporal trends in LST (Ebrahimy et al., 2021), provides valuable information on surface temperature obtained from satellite observations. Specifically, the dataset used for this study filtered daily global LST data with a spatial resolution of 1 kilometer for five consecutive months from January to May in the years 1993, 2003, 2013, and 2023 within the study area.

3.7 .Image classification and analysis

Within the GEE platform, all essential procedures such as image preprocessing, classifier selection, land use/land cover classification, NDVI computation, NDII, density slicing, linear regression model development, Mann-Kendall trend test, and accuracy assessment were conducted. The methodology flowchart (Figure 3.4) visually depicts the sequential steps undertaken in this study to achieve the defined objectives.

For specific tasks related to area calculation, density slicing, and map preparation, QGIS version 3.2, ArcGIS Pro version 3.0, and ArcGIS version 8 were utilized. Additionally, these software tools were employed for advanced spatial analysis, geoprocessing, data visualization, creating high-quality cartographic outputs, and performing temporal analysis to assess changes over time. To generate charts and graphs, along with some statistical calculations, Microsoft Excel and its add-ins, such as XLSTAT, were used. The methodological approach employed in this study is illustrated in the subsequent flowchart (Figure 3.4).

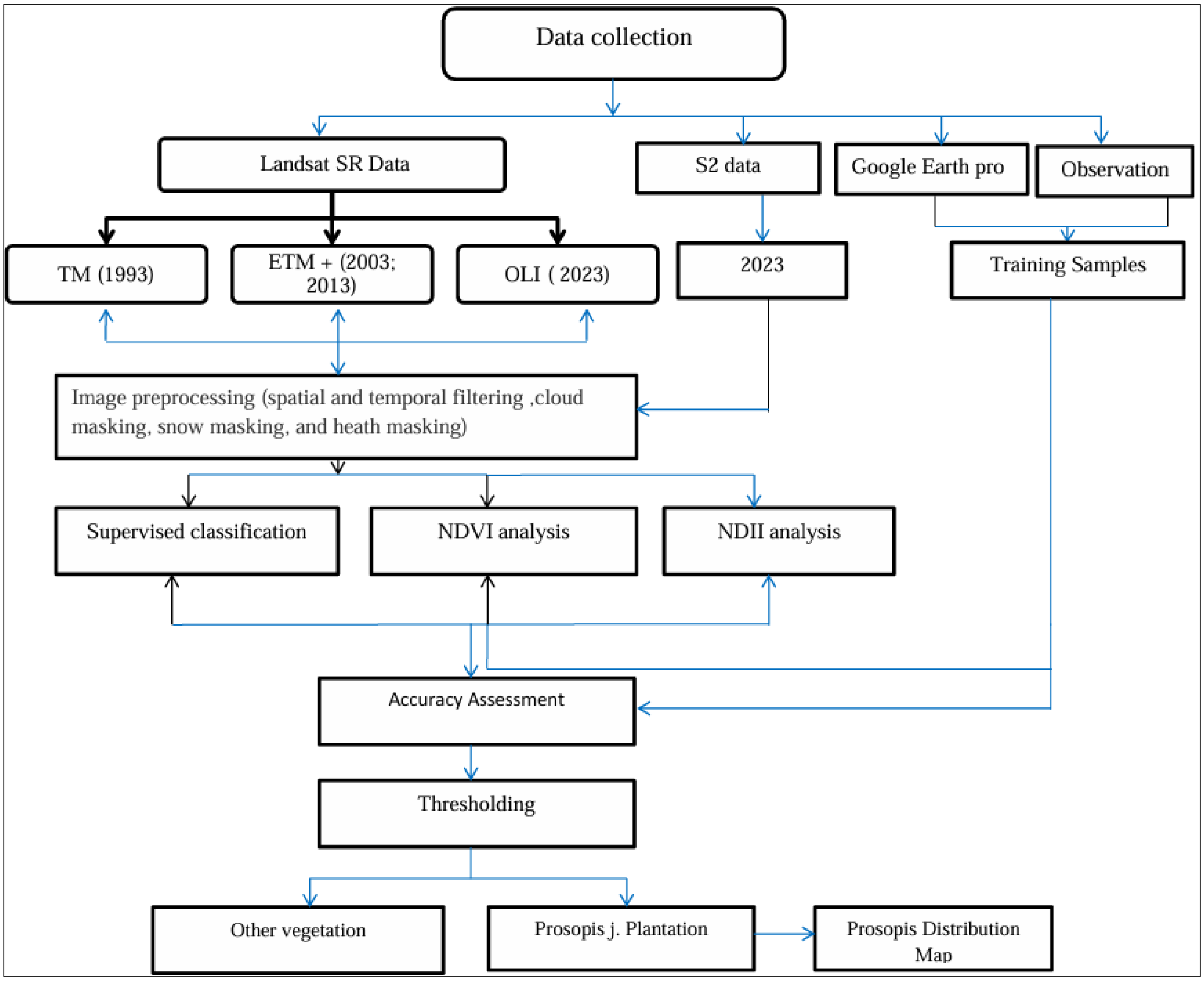


Figure 3. 3: The methodology flow chart

3.7.1 Classification methods

Table 3.4 presents the main LULC class structure for the study area, which consists of six primary classes: Prosopis juliflora, other vegetation, cultivated land, built-up areas, water bodies, and bare land. In the Awash Fentale District, grazing land is not classified as a separate entity but is included within areas categorized as "Open Bush and Shrub Land." Livestock may graze on natural vegetation or crop residues, leading to a situation where grazing is inherently part of these broader categories.

The determination of land cover classification for these classes involved utilizing well-known classification methods, specifically random forest (RF) classifiers. This classifier was selected to achieve the highest level of accuracy while working on the GEE platform. To ensure sufficient data availability for the specified time period, the classification process incorporated imagery from Landsat 5, Landsat 7, Landsat 8, and Sentinel 2.

After assessing performance stability and evaluating feature importance, RF machine learning algorithms, a type of supervised classification technique, were employed to categorize land use and land cover. RF effectively handles outliers and noisy datasets and performs well with high-dimensional and multi-source datasets, achieving greater accuracy than other classifiers like support vector machines (SVM) and maximum likelihood classification (MLC) (Belgiu & Drăguț, 2016). RF is an extension of decision tree techniques and operates by utilizing bootstrapping and bootstrap aggregation, also known as bagging. The fundamental idea involves running multiple iterations of a predictor or classifier to arrive at a final decision through a majority vote among the predictors. Accuracy generally improves with an increasing number of predictors until it reaches a point where it begins to decline.

To construct the trees, the training data is bootstrapped, meaning that random samples are selected with replacement. However, not all samples are used to grow each tree. The discarded samples within the bootstrapped sample are considered out-of-bag (OOB) data. During the construction of each tree, only a randomly chosen set of input features is evaluated at each node. The OOB data is then utilized to calculate the classification error rate and determine the significance of the input variables (features) as new trees are added to the forest. Once all the trees are built, a majority vote among them is used to classify a given case, similar to the concept of bootstrap aggregating (Kulkarni & Lowe, 2016).

To conduct supervised classification, training samples were collected for each class using pixel-based analysis. These samples were gathered from high-resolution Google Earth Pro, field observations, and the MCD12Q1 LC_Type1 dataset, which is produced by the Terra and Aqua combined Moderate Resolution Imaging Spectroradiometer (MODIS) Land Cover Type (MCD12Q1) Version 6.1 data product. This dataset provides global land cover types at yearly intervals (Mark Friedl et al., 2015) and was considered to obtain representation of different land use and land cover categories. Additionally, images and observations captured during a field visit were utilized.

The classification of vegetation cover, which encompasses the distribution, density, and diversity of shrub and tree species, resulted in the identification of six distinct classes. The initial class, known as Prosopis juliflora, was visually distinguished by its dense, uniform patches. Unlike other species in the region that experience leaf drying or shedding in the dry season, Prosopis juliflora maintains its evergreen nature year-round, leading to unique spectral reflectance characteristics. The reflectance pattern of land invaded by Prosopis juliflora displayed a vibrant red hue, which was notably distinct from other land use and land cover categories observed in the study area.

The study utilized a satellite image taken during the months of January to May, which aligns with the relatively dry season in the region. The second category consisted of various vegetation types, such as non-Prosopis juliflora trees, bushes, and scattered instances of Prosopis juliflora. Cultivated land, including both developed and fallowed areas, was represented by the third category. The fourth class encompassed built-up areas, such as different types of settlements and roads. Water bodies, including all detectable terrestrial water bodies observed by remote sensors, were classified as the fifth category. Lastly, the sixth class referred to bare land areas that appeared devoid of considerable vegetation.

Table 3. 4 : An overview of the various land use and land cover types within the study area.

LU/LC types	Description
Open bush and Shrub land	Includes natural and fragmented bushy vegetation where livestock graze and browse. It also has regions dominated by woody vegetation, including true shrubs, young trees, and small or stunted plants due to environmental conditions.
Cultivated land	Encompasses cultivated lands with herbaceous crops, as well as woody areas such as orchards, nurseries, and cotton farms, along with settlement areas within the research site.
Built up land	Different types of settlements, constructions, and roads
Water	An area saturated with water, encompassed by trees, shrubs, and other vegetation.
Bare land	Consisting of exposed soil, degraded terrain, rocky surfaces, and areas with sparse vegetation or limited presence of plant life.
Prosopis juliflora Invaded land	Regions primarily occupied by a non-native evergreen tree species called Prosopis juliflora , with an average tree density.

Source : Anderson, J. R. (1976)

For the Prosopis juliflora class, a total of 200 points were sampled, with 50 sample points collected for each time point. The remaining classes had 1,000 points sampled, with 50 samples collected for each time point as well. For the earlier time periods, GCP points were derived from historical satellite imagery and local field surveys, providing valuable insights into land cover and land use patterns from that time. By utilizing these historical datasets, it is possible to identify and validate the presence of Prosopis juliflora and other land cover classes. To allocate training and validation samples, an 80-20 split was employed (80% for training and 20% for testing).

The study utilized the RF algorithm within the GEE framework(Annex 2). To generate a prediction model using the RF classifier, only two parameters need to be defined: the desired number of classification trees, denoted as n (ntree), and the number of prediction variables, denoted as m (mtry), used in each node to grow the tree (Rodriguez-Galiano et al. 2012).

To accomplish this, a temporally median composite image was created using the cloud-based GEE platform (Tamiminia et al., 2020). Data from the Landsat archive, collected during four different time points (1983, 2003, 2013, and 2023) between January and May, were utilized to generate the classified image. The platform's atmospherically corrected surface reflectance data facilitated direct application in image classification.

3.8 Assessment of Photosynthetic activity of Prosopis juliflora

The analysis of vegetation photosynthetic activity and biomass often involves the use of NDVI, a widely utilized tool (Gamon et al., 1995). NDVI is a reliable indicator of the radiation absorbed by actively growing plants. It measures the strong absorption of red light and the strong reflection of near-infrared light by vegetation. To calculate satellite-based NDVI, reflectance measurements in the near-infrared (NIR) and red (R) regions of the electromagnetic spectrum are used in the following formula:

$$NDVI=\frac{NIR-R}{NIR+R} \quad \ldots\ldots \quad (1)$$

where R is the reflectance in the red band, and NIR is the reflectance in the near-infrared band (Qi, J., et al.,1994).

The NDVI can be a valuable tool in differentiating Prosopis juliflora plantations from the surrounding vegetation. NDVI measures the reflectance of NIR and red light by plants, providing insights into their health and density. Healthy vegetation tends to reflect more NIR light and absorb more red light, resulting in higher NDVI values. By comparing NDVI values, we can identify areas with dense and active vegetation, such as Prosopis juliflora plantations, which exhibit distinct NDVI patterns compared to other vegetation types (Bannari et al.,1995). The NDVI was used to identify the vegetation types which were photosynthetically active during the drought periods. These vegetation types were most likely Prosopis juliflora plants.

3.9.Assessment of the Distribution of Prosopis juliflora using NDII

The NDII is a ratio of foliar water content to actual water content. In this study, data processing was conducted using the GEE platform. The reflectance of the shortwave infrared band (SWIR) is influenced by the moisture content of vegetation leaves and soil moisture. Previous research has shown that SWIR reflectance is significantly affected by the internal structure and dry matter content of vegetation leaves (Gang et al., 2020).

The NDII is commonly used as an index for remotely sensing the Equivalent Water Thickness (EWT) of leaves and canopies. It is important to note that foliar water content represents only a fraction of the total Vegetation Water Content (VWC). To calculate EWT, foliar water content is divided by the density of liquid water. EWT is valuable for understanding the relationship between leaf EWT, leaf area index (LAI), and canopy EWT. As leaf water content increases, SWIR reflectance generally decreases (Seelig et al., 2008).

The NDII is derived from remote sensing data by analyzing the NIR and SWIR wavelengths (Ji, L. et al., 2014). According to Klemas & Smart (1983), the NDII provides useful information about Prosopis juliflora plantation by comparing reflectance values in these spectral bands. The NDII is defined as:

$$\mathrm{NDII} = \frac{\mathrm{NIR}-\mathrm{SWIR}}{\mathrm{SWIR}+\mathrm{NIR}} \quad \ldots\ldots \quad (1)$$

The reflectance of NIR and SWIR is denoted as NIR and SWIR, respectively. Specifically, the NIR band data used in this study were obtained from band 4 of the TM/ETM+ sensor and band 5 of the OLI sensor. Similarly, the red band data were derived from band 3 of the TM/ETM+ sensor and band 4 of the OLI sensor. Additionally, the SWIR band data were collected from band 5 of the TM/ETM+ sensor and band 6 of the OLI sensor.

Table 3. 5: Comparison between Landsat 5 TM, Landsat 7 ETM+, Landsat 8 OLI, and Sentinel-2 MSI bands.

Bands	Landsat 5 TM		Landsat 7 ETM+		Landsat 8 OLI		Sentinel 2 MSI	
	Wl(µm)	R(m)	Wl(µm)	R(m)	Wl(µm)	R(m)	Wl(µm)	R(m)
Red	0.63 – 0.69	30	0.63-0.69	30	0.64-0.67	30	0.64-0.67	10
Green	0.52 – 0.60	30	0.52-0.60	30	0.53-0.59	30	0.55-0.58	10
Blue	0.45 – 0.52	30	0.45-0.52	30	0.45-0.51	30	0.46-0.52	10
NIR	0.76 – 0.90	30	0.76-0.90	30	0.85-0.88	30	0.78-0.90	10
SWIR -1	1.55 – 1.75	30	1.55-1.75	30	1.57-1.65	30	1.57-1.1.65	20
SWIR -2	2.08 – 2.35	30	2.08-2.35	30	2.11-2.29	30	2.10-2.28	20

Source: EOS Data Analytics,2024.

3.10. Accuracy Assessment

The accuracy computation was performed using the GEE platform for LULC type classification. The most commonly employed method for accuracy assessment is based on the confusion matrix, as stated by Stehman and Foody (2009). In this study, an independent test sample set was used to evaluate the accuracy of the classified images, ensuring it was distinct from the training sample sets. The test samples were distributed using equal-area stratified random sampling, resulting in a uniform global distribution and a random local distribution of validation samples, as mentioned by Li et al. (2021). The RF algorithms were applied to Landsat 5, 7, and 8, as well as Sentinel 2 images, and the resulting classified images were evaluated using a confusion matrix, comparing the classes assigned by the classifiers to the true classes using JavaScript in GEE.

From the derived confusion matrices, the accuracy of the classified images was assessed using four commonly used accuracy measure indices: overall accuracy (OA) (Eq. (1)), user accuracy

(UA) (Eq. (3)), producer accuracy (PA) (Eq. (4)), and kappa coefficient (K) (Eq. (2)). These indices were evaluated by comparing the accuracy of the classified images with commonly used quality metrics, as discussed by Loukika et al. (2021).

$$OA = \frac{\text{Number of Correctly Classified Samples}}{\text{Number of Total Samples}} * 100 \quad (1)$$

The overall accuracy is a measure of how well a reference sample is classified by comparing the number of correctly classified samples to the total number of samples. It gives a percentage of the reference sites that were correctly mapped out from the entire data set (Congalton,R.G. 1991).

$$K = \frac{N \sum_{i=1}^{r} Xii - (Xi + \times X + i)}{N^2 - \sum_{i=1}^{r} (Xi + \times X + i)} \quad (2)$$

The kappa coefficient (K) is determined using Equation (2), where r represents the number of rows and columns in the error matrix, Xii represents the number of observations in row i and column i, Xi+ represents the marginal total of row i, X + i represents the marginal total of column i, and N represents the total number of observations. The kappa coefficient measures the degree to which the accuracy in a classification system exceeds what would be achieved by random chance. Furthermore, the user accuracy (UA: Equation (3)), producer's accuracy (PA: Equation (4)), and F1 Score (Equation (5)) at the class level were used (Congalton,R.G. 1991)

$$UA = \frac{\text{Number of Correctly Classified Samples in Each class}}{\text{Number Samples Classified to That Class}} \quad (3).$$

$$PA = \frac{\text{Number of Correctly Classified Samples in Each class}}{\text{Number Samples from Reference Data to that Class}} \quad (4).$$

3.10.1. Assessing impact of climatic factors on the propagation and growth of Prosopis juliflora

The temporal patterns of precipitation and temperature in the study area were evaluated against the mean NDVI of Prosopis juliflora. The NDVI mean served as an indicator of vegetation photosynthetic activity and the regenerative capability of Prosopis juliflora plants. Simple linear regression analysis was conducted at a significance level of $p < 0.05$ to model the relationship between the independent variables precipitation (mm) and temperature (°C) and the dependent variable NDVI.

Prosopis juliflora productivity datasets from 1993 to 2023 and climatic data (average temperature and total rainfall) were plotted against time at four different sites in order to identify trends across the study period. Correlation analyses were performed to determine the longitudinal relationships between trends in rainfall, temperature, Prosopis juliflora, and other vegetation cover.

3.11. Effects of Prosopis juliflora Expansion on Rural Livelihoods in the Awash Fentale District

3.11.1. Livelihoods Data collection

In this study, a comprehensive set of data collection techniques was employed to ensure the acquisition of relevant and accurate information. The methodologies utilized included focus group discussions (FGDs), household surveys, and key informant interviews (KIIs). The research was conducted in the Awash Fentale District, specifically targeting two kebeles: Kebena, which is significantly affected by the invasion of Prosopis juliflora, and Didub, which experiences a relatively lower level of invasion. These kebeles were purposefully selected to facilitate a comprehensive understanding of the impacts of this invasive species.

A total of seventy participants were randomly selected for the survey, with thirty-five respondents from each kebele. The sample comprised 66% male and 34% female household heads, representing a diverse age range that included groups aged 18–30, 31–40, 41–50, and 51–70 years. This stratified sampling approach aimed to capture a broad spectrum of perspectives and experiences related to the livelihood impacts of Prosopis juliflora in the region. In rural Ethiopian settings, these groupings align with sociocultural structures where individuals of these age brackets play distinct roles in households and community activities.

3.11.2. Livelihoods Data analysis

The data collected from household heads in the Didub and Kebena kebeles were analyzed to assess the livelihood implications of Prosopis juliflora. The gender distribution among respondents revealed a predominance of males, comprising 69% in Didub and 66% in Kebena, while females accounted for 31% and 34%, respectively. Notably, 40% of the respondents fell within the 31-40 age group, indicating a significant level of socio-economic engagement among younger adults. Conversely, only 5.7% of participants were aged 50-70, suggesting lower participation rates among older individuals. The primary occupation identified by the majority of respondents was pastoralism, reported by 70% of participants, followed by agro-pastoralism at 20%, trade, and other activities at 5%.

The analysis of household perceptions regarding key socio-economic aspects of Prosopis juliflora revealed significant differences in how respondents viewed its various impacts and benefits. This analysis explored a range of aspects that reflect the plant's complex interactions with the local economy, environment, and livelihoods.

On the positive side, many respondents acknowledged that Prosopis juliflora plays a significant role in enhancing fodder availability for livestock, particularly during dry seasons when other forage resources are scarce. Additionally, its utility as a reliable source of fuelwood was widely recognized, offering an accessible energy resource for household cooking and heating needs. Some respondents also highlighted its potential to mitigate climate impacts by reducing soil erosion, contributing to shade provision in hot and arid climates, and improving soil fertility in areas where its organic matter enriches the soil. Furthermore, for economically disadvantaged households, the plant serves as a source of income, with opportunities to sell its wood, pods, or other byproducts to local markets.

However, the negative impacts of Prosopis juliflora were equally emphasized. Many respondents expressed concerns about its aggressive competition with native pasture species, which threatens the availability of traditional grazing lands and undermines livestock productivity. The plant's invasive nature often leads to the loss of biodiversity, altering ecosystems that are vital for local livelihoods. Another significant issue raised was the health problems it causes in livestock, such as dental damage or digestive issues when animals consume its pods excessively. Nevertheless, some respondents noted that it indirectly increases income from livestock, as its fodder can improve livestock resilience during dry periods, potentially enhancing market value. Lastly, the plant's use in house construction, particularly for roofing and fencing, was mentioned as a practical but limited benefit.

Survey data collected from the Didub and Kebena Kebeles illustrated the mixed opinions within the community regarding Prosopis juliflora. While some households acknowledged its economic and environmental benefits, others strongly criticized its invasive tendencies and associated challenges. This dichotomy underscores the plant's dual nature—acting as both a valuable resource and a significant threat to sustainable livelihoods, livestock management, and environmental health in the region. The findings emphasize the need for balanced management strategies that mitigate its negative impacts while optimizing its potential benefits for local communities.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Spatial distribution and trends of Prosopis juliflora

4.1.1 Classification and Evaluation of Accuracy

The overall accuracies for the years 1993, 2003, 2013, and 2023 were found to be 0.88, 0.85, 0.87, and 0.88, respectively(Annex 1). The producer's accuracies for the individual classes of the classified map varied from 75%(bush and shrubs) to 100% (Prosopis juliflora), 82%(Prosopis juliflora) to 90% (cultivation),71% (bare land) to 100% (Prosopis juliflora), and 67%(built-up areas) to 100% (Prosopis juliflora) in the years 1993, 2003, 2013, and 2023, respectively (Annex 1). Similarly, the user's accuracies for the individual classes ranged from 72% (Prosopis juliflora) to 100% (bush and shrubs), 78% (cultivation) to 100% (water body), 73% (built-up) to 100% (Prosopis juliflora), and 80% (cultivation) to 100% (water, bare land and built-up) for the years 1993, 2003, 2013, and 2023, respectively.

4.1.2 Comparison of Classification Effectiveness Between Landsat 8 and Sentinel-2 Imagery

This research presents a comparative analysis of land cover classification between Landsat 8 and Sentinel-2 imagery, focusing on their effectiveness in detecting and mapping Prosopis juliflora. The findings reveal that Sentinel-2 imagery results in more precise land cover classification due to its enhanced spatial resolution and improved spectral capabilities. The overall classification accuracy was recorded at 90% for Landsat 8 and 97% for Sentinel-2, indicating the superiority of the latter in capturing finer details and differentiating between similar vegetation types. In line with this, Ghayour et al. (2021) indicated that Sentinel-2 consistently achieved higher accuracy levels compared to the Landsat 8 datasets, regardless of the classifier employed.

4.1.3 True Color and False Color Composites

The visual context provided by TCC and FCC (Figures 4.1, Landsat imagery, and 4.2, Sentinel 2 imagery) aids in validating classification results. Khawfany et al. (2017) utilized a comparable approach by employing FCC and TCC techniques to map mangrove ecosystems on Kelapan

Island. This combination of imaging techniques effectively highlights the unique characteristics of the mangrove canopy, allowing it to be clearly distinguished from other land cover types.

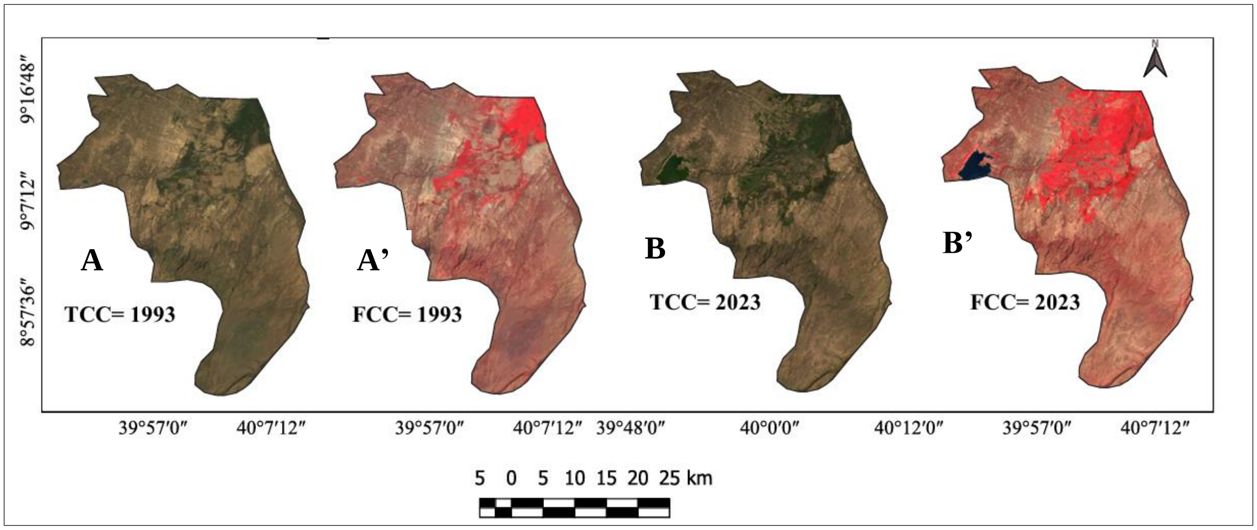
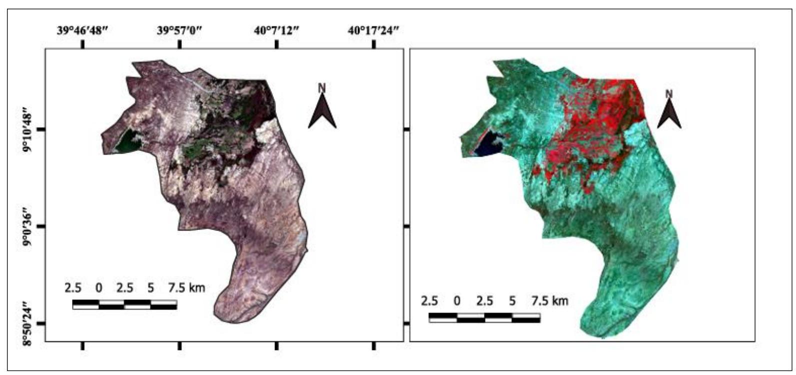


Figure 4. 1**:** Landsat versions TCC (A & B) and FCC (A' & B') for the initial year, 1993, and the final year, 2023, which were used as part of the classification clues.

Figure 4. 2 :Map showing TCC(left) and FCC (right) of the same year(2023).



4.1.4 Spatial Extent of LULC Types in the Awash Fentale District from 1993 to 2023.

In the Awash Fentale District, a total of six LULC types were identified for the years 1993, 2003, 2013, and 2023 (Figure 4.3 and Table 4.1). The total LULC area of the District is 1,058 km². In 1993, open bush and shrubs were the predominant LULC type, accounting for 57% of the total area. This was followed by cropland (22.2%) bare land (6.5%), and Prosopis juliflora (6%). During this period, the distribution of Prosopis juliflora was primarily concentrated in the northeastern part of the District, particularly in the kebeles of Kebena and Bolodita (Figure 4.3), where it thrived along the Awash River and irrigated lands. Smaller proportions of the LULC area were occupied by built-up areas, which represented 5.8%, and water bodies, accounting for 2.5% (Table 4.1).

In 2003, open bush and shrubs remained the most dominant LULC type in the Awash Fentale District, representing 49.7% of the total area. This was followed by cultivation at 23.2%. Built-up areas comprised 9.5%, while bare land represented 7.2%. Smaller proportions were occupied by Prosopis juliflora at 6.3% and water bodies at 4.1% (Table 4.1). In 2013, the trends persisted, with open bush and shrubs and cultivation continuing to be the most prominent types, comprising 49.0% and 24.2%, respectively. Built-up areas increased slightly to 10.1%, while Prosopis juliflora also rose to 7.3%. Bare land and water bodies occupied smaller shares of the area, at 6.0% and 3.4%, respectively.

By 2023, open bush and shrubs and cultivation remained the leading land cover types, accounting for 48.6% and 24.6%, respectively. The proportion of built-up areas further increased to 10.5%, and Prosopis juliflora rose to 8.3%. Conversely, bare land and water bodies represented smaller shares of the total area, at 4.3% and 3.7%, respectively (Table 4.1).

Overall, these changes reflect the dynamic nature of LULC in the Awash Fentale District over the study periods. The increase in Prosopis juliflora coverage from 6% in 1993 to 8.3% in 2023 is driven by its ecological adaptability and resilience in arid conditions. The results demonstrate the expansion of Prosopis juliflora during the study period. Shiferaw et al. (2019) also reported similar results.

Table 4. 1: Prosopis juliflora and other land use types in the Awash Fentale District for the years 1993, 2003, 2013, and 2023.

No	Lulc Types	1993		2003		2013		2023		Between 1993 and 2023	
		Km^2	%	Km^2	%	Km^2	%	Km^2	%	Km^2	%
1	Prosopis j.	63.0	6.0	66.2	6.3	77.0	7.3	87.3	8.3	24.3	2.3
2	Open B.and Shrubs	602.6	57.0	525.8	49.7	518.3	49.0	513.8	48.6	-88.8	-8.4
3	Cultivation	235.7	22.2	245.3	23.2	256.0	24.2	260.4	24.6	24.7	2.4
4	Built-up	61.5	5.8	100.9	9.5	106.6	10.1	112.3	10.5	50.8	4.7
5	Water	26.6	2.5	43.7	4.1	36.1	3.4	39.1	3.7	12.5	1.2
6	Bare land	68.6	6.5	76.1	7.2	64.0	6.0	45.1	4.3	-23.5	-2.2
	Total	1058	100	1058	100	1058	100	1058	100		

Table 4. 2: Spatial distribution of Prosopis juliflora and other LULC types in the Awash Fentale District as observed by Sentinel 2 in 2023.

S.No	Lulc Types	Land size(Km^2)	
		2023	% of Total
1	Prosopis juliflora j.	91.9	8.7
2	Open Bush and Shrubs	544.2	51.4
3	Cultivation	171.4	16.2
4	Built-up	154.4	14.6
5	Water	30.1	2.8
6	Bare land	66.0	6.2
	Sum	1058	100

The differences in the LULC (Land Use Land Cover) classification results between Landsat 8 (4.1) and Sentinel-2 (4.2) imagery can be attributed to factors such as Landsat 8 has a spatial resolution of 30 meters (except for the panchromatic band, which has a resolution of 15 meters), whereas Sentinel-2 offers higher spatial resolution, with bands at 10 meters, 20 meters, and 60 meters. This finer resolution in Sentinel-2 enables it to capture smaller land cover features more accurately, potentially resulting in more detailed classifications compared to Landsat 8.

4.1.5 Changes in Prosopis juliflora in the Awash Fentale District (1993–2023)

Prosopis juliflora showed a steady increase in coverage from 6.0% in 1993 to 8.3% in 2023, reflecting an overall rise of 2.3% over the 30 years period, with consistent growth each decade (Table 4.1). In contrast, open bush and shrubs experienced a notable decline from 57.0% to 48.6%, indicating a reduction of 8.4% overall, with the most significant decrease occurring between 1993 and 2003 (7.3%).

Cultivation saw a slight increase from 22.2% in 1993 to 24.6% in 2023, totaling a change of 2.4%, particularly notable between 2013 and 2023, with an increase of 0.4%. Meanwhile, Built-up Areas rose significantly from 5.8% to 10.5%, marking an increase of 4.7%, with the largest growth occurring between 1993 and 2003 at 3.7%. Water Bodies increased from 2.5% to 3.7%, showing a total increase of 1.2%, although a slight decrease of 0.7% occurred between 2003 and 2013. Conversely, Bare Land decreased from 6.5% to 4.3%, indicating a decline of 2.2%, particularly pronounced from 2013 to 2023, with a drop of 1.7%

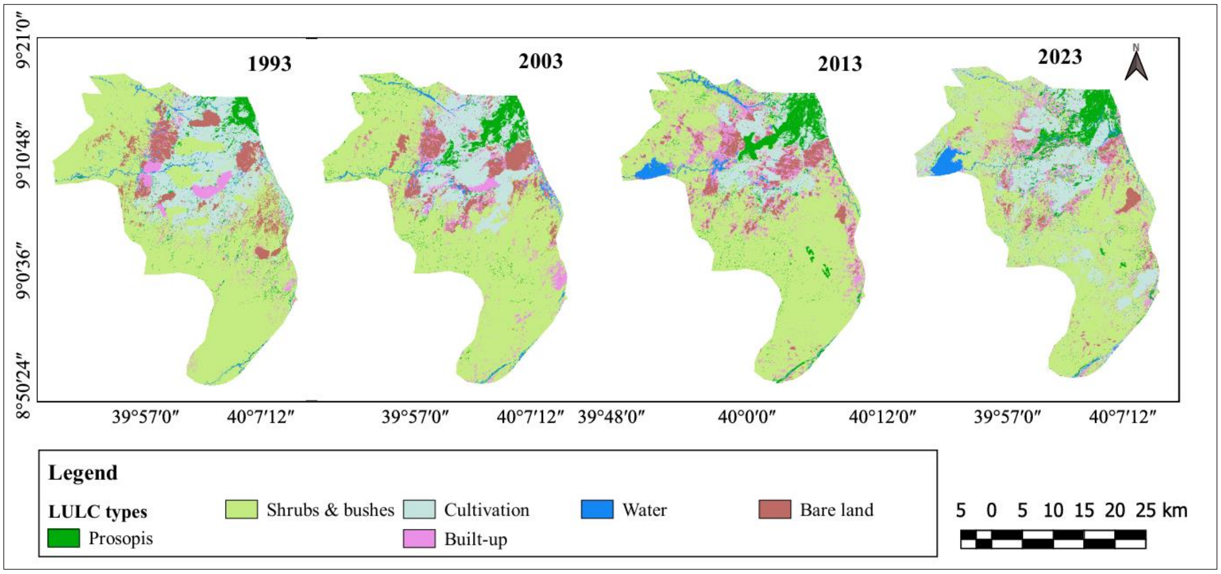


Figure 4. 3: LULC classification for 1993, 2003, 2013, and 2023 derived from Landsat imagery.

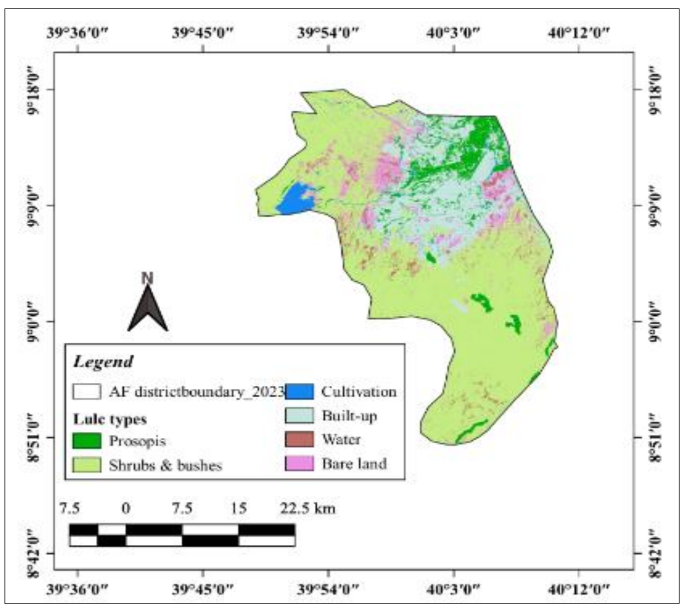


Figure 4. 4: LULC classification derived from Sentinel-2 images for 2023.

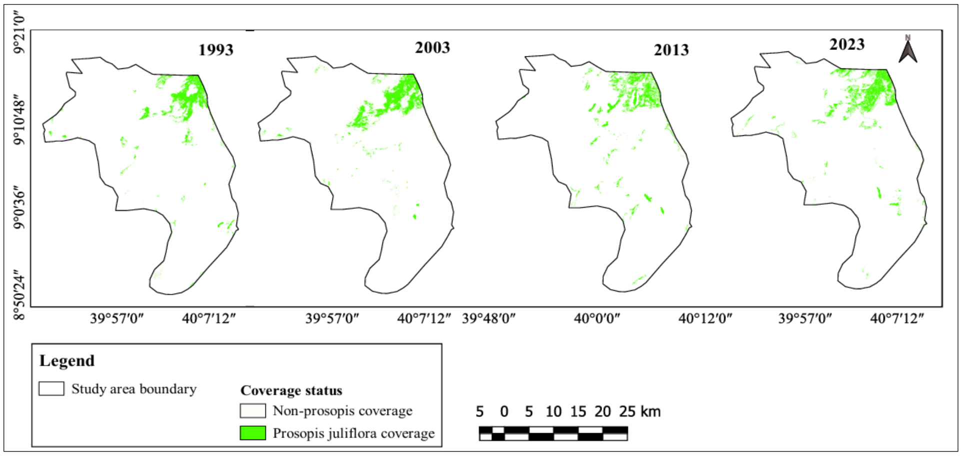


Figure 4. 5 : Illustrates the distribution of the Prosopis juliflora species within the study area at designated time points.

The results of this study show a continuous increase in the area invaded by Prosopis juliflora over a 30-year period, from 1993 to 2023 (Figure 4.5). Specifically, the coverage of this invasive species grew from 63 km² in 1993 to 87.3 km² in 2023, indicating significant expansion within the studied area. This growth corresponds to a percentage change, rising from 6% to 8.3% over the same period. These findings suggest that Prosopis juliflora is becoming increasingly dominant in the landscape, raising concerns about its potential impact on grazing land, encroachment on agricultural land, and hindrance to community connectivity by road.

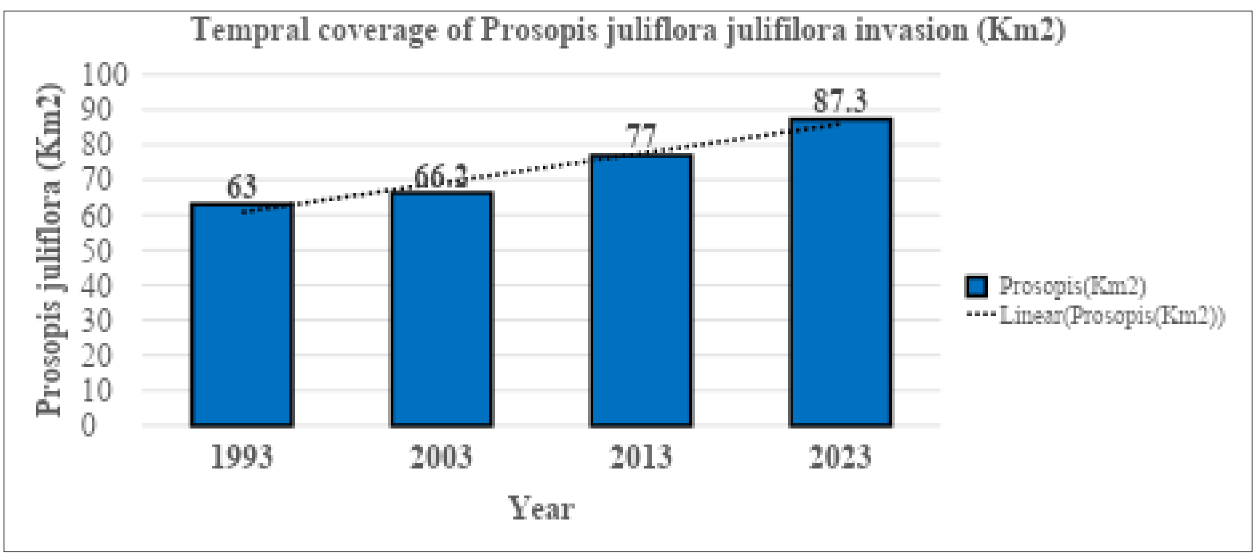


Figure 4. 6: Bar graph showing Prosopis juliflora's temporal invasion.

This invasive species is primarily concentrated in the northeastern part of the district, where the areas of Diho, Bolodita, and Kebena kebeles are highly affected. These areas are connected to the Awash River, and the proximity to this water source likely favors the growth of this invasive species, allowing it to establish and expand effectively in these fertile regions. A study by Shiferaw et al. (2018) highlights the role of water availability in facilitating the growth of the invasive species Prosopis juliflora, which adversely affects local biodiversity and agricultural practices. The influence of wild animals, as well as domestic animals like goats and sheep, is also considerable in triggering the expansion of this alien plant. Overall, the findings highlight the ongoing spread of Prosopis juliflora in the district, emphasizing the need for monitoring and management strategies to address the implications of this expansion on the environment and local communities.

4.2.Spectral Curve for identification of Prosopis juliflora plantation

Remote sensing involves measuring radiation that is either reflected or emitted by various objects. The variations in this radiation allow for the differentiation of surface features or materials through the analysis of their spectral reflectance patterns or signatures. These signatures can be graphically represented as spectral curves. Within the study area, the different land cover types represented by the spectral curve (Figure 4.7) include Prosopis, Open Bush and Shrubs, Cultivation, Built-up Areas, Water, and Bare Land.

In the case of Landsat 8 OLI, Prosopis juliflora displays low reflectance in the red light (SR_B4) spectrum and high reflectance in the near-infrared (SR_B5) spectrum. For Landsat 7 ETM+ and Landsat 5 TM, it exhibits low reflectance in the red light (SR_B3) spectrum and high reflectance in the near-infrared (SR_B4) spectrum. Open Bush and Shrubs have relatively higher red-light reflectance and slightly lower near-infrared reflectance compared to healthy Prosopis juliflora. Cultivation shows high red-light reflectance and significantly lower near-infrared reflectance compared to Prosopis juliflora. Water has minimal red-light reflectance and very low near-infrared reflectance. Bare Land is characterized by high red-light reflectance and low near-infrared reflectance.

The interannual data presented in Figure 4.7 demonstrate a consistent trend in which the extent of Prosopis juliflora is clearly identifiable from other LULC types. A study conducted by Ragavan (2015) successfully quantified the invasion of Prosopis juliflora in the Palayamkottai taluk during the years 2007 and 2012 by employing the same techniques. This suggests that the developed techniques and methodologies using Google Earth Engine can be utilized for tracking and modeling vegetation species in other areas within the country. Additionally, the slicing technique described in the following paragraphs can be employed to extract the target species.

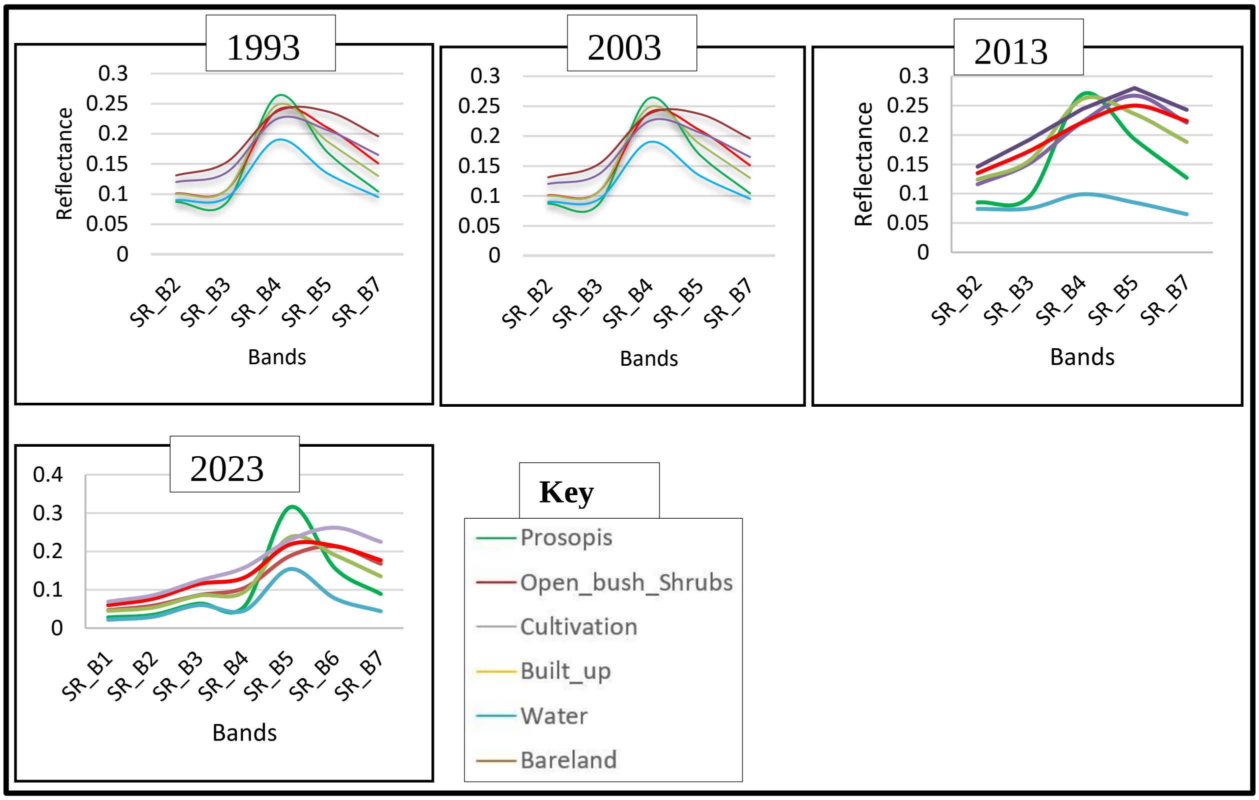


Figure 4. 7:Spectral response comparison of LULC across various Landsat Bands.

4.3.NDII slicing to indicate spatial distribution of Prosopis juliflora

The results of density slicing applied to the NDII image, which was computed in Google Earth Engine, are presented in Figure 4.8 using a histogram stretch in ArcGIS Pro. The threshold for all time points was established at NDII values of ≥ 0.2 to identify areas predominantly invaded by the invasive species Prosopis juliflora , in comparison to other locations within the study area. This determination was based on field observations and references from Google Earth Pro; furthermore, the image capturing occurred during the dry season, a period when many native species typically exhibit lower NDII values due to reduced moisture content, whereas Prosopis, being highly drought-resistant, maintains higher NDII levels. As the NDII value approaches +1, it indicates a higher canopy water content, which aids in identifying evergreen trees in the area, specifically Prosopis juliflora in this case. So, upon applying the slicing technique to isolate

NDII values equal to or greater than 0.2, the northwestern part of the study area reveals a vibrant and lush green color, indicating dense vegetation cover.

The primary reason for this remarkable greenness can be attributed to the expansion of Prosopis juliflora , a highly adaptive and invasive plant species. The northwestern area provides favorable conditions for the growth and spread of Prosopis juliflora , due to access to water sources such as Awash river and irrigation channels.

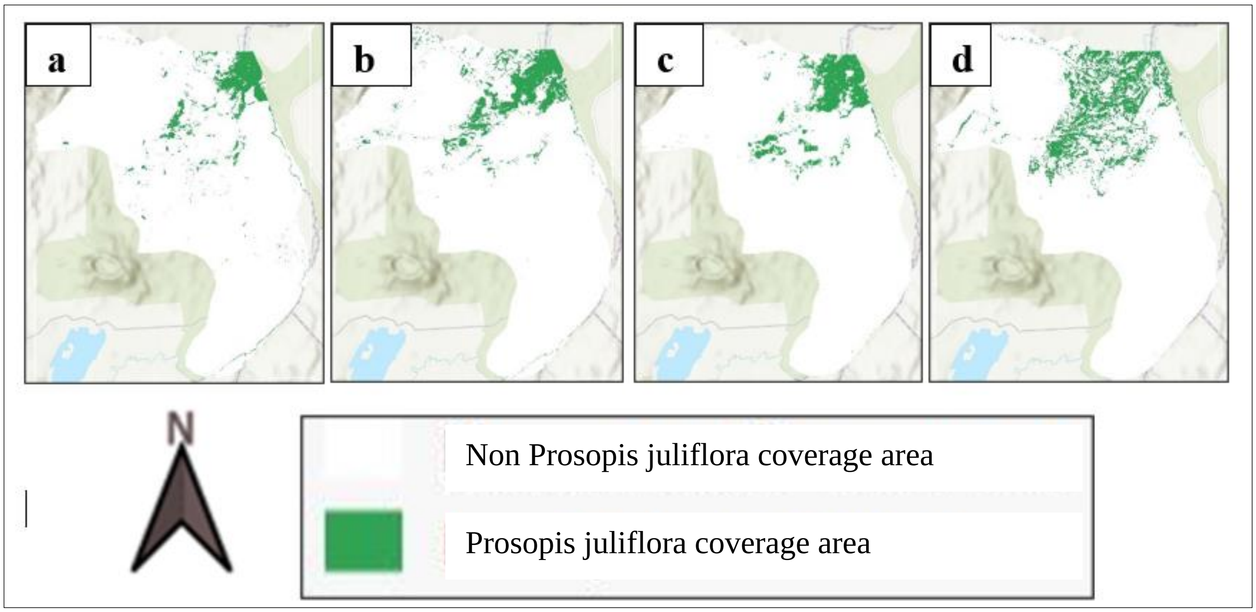


Figure 4. 8: Density-sliced coverage map of Prosopis juliflora for 1993 (a), 2003 (b), 2013 (c), and 2023 (d).

4.4.NDVI for Identifying Prosopis juliflora Plantations in the AF District.

The mean NDVI values were systematically computed using various versions of Landsat satellite imagery across multiple time periods to assess the vegetation dynamics associated with Prosopis juliflora plantations in the AF District. The analysis revealed that in 1993, the NDVI values ranged from -0.06 to 0.77. By 2003, the NDVI values exhibited a broader range of 0.00 to 0.83, suggesting fluctuations in vegetation cover. In 2013, the range shifted slightly to -0.29 to 0.69, reflecting ongoing changes in land cover. This decline may be attributed to significant alterations in climatic conditions, such as reduced rainfall and elevated temperatures experienced in the study area during that time. Most recently, in 2023, the NDVI values varied from -0.38 to 0.78 for Landsat OLI imagery and from -0.57 to 0.92 for Sentinel-2 imagery, indicating significant variation between the two sensors. The maps illustrated in Figures 4.9 and 4.10 were derived from Landsat and Sentinel-2 image data, respectively.

In both cases, the maps prominently display areas of substantial positive NDVI values highlighted in green and yellow, which serve as indicators of vegetation cover in the area. These areas encompass the northeastern parts of the District, extending toward the center along the irrigated area and the Awash River. Higher NDVI values correlate with denser vegetation, likely due to the spread and encroachment of Prosopis juliflora, particularly along the banks of drainage systems where moisture is more readily available. Notably, field observations suggest that sites exhibiting mean NDVI values exceeding 0.6 are predominantly characterized by the presence of Prosopis juliflora, especially when applying a threshold value of 0.6. This analysis underscores the efficacy of NDVI as a valuable tool for monitoring and identifying Prosopis juliflora plantations and provides critical insights into the ecological implications of its spread within the AF District.

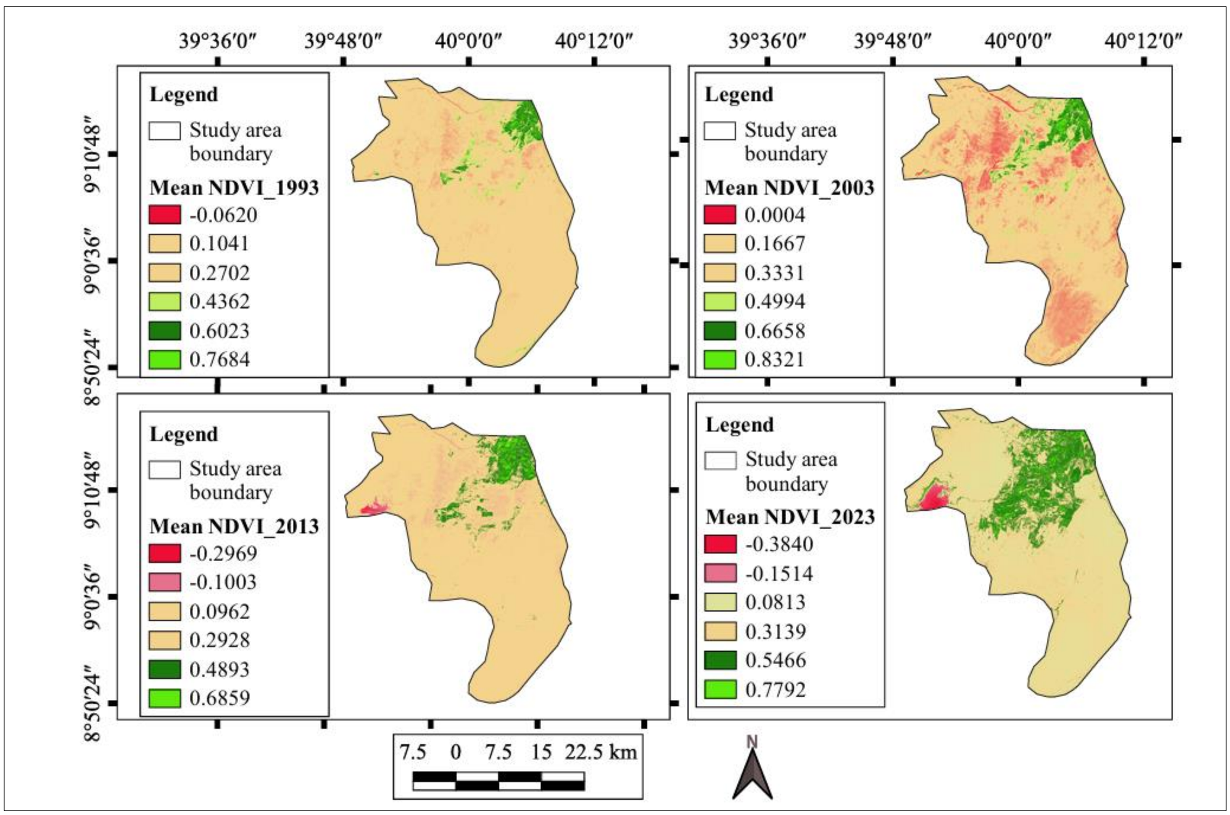


Figure 4. 9 : Mean NDVI of Landsat imageries analyzed for the years 1993, 2003, 2013, and 2023.

Both Figure 4.9 and Figure 4.10 (Landsat and Sentinel 2 for the 2023 point in time) reveal nearly identical areas of spatial coverage, stretching from the southwest to the northeast. This pattern closely follows the Awash River and the irrigated riverbanks. Negative values are prevalent in the northwestern, southern, and southeastern areas, covering large portions of these region

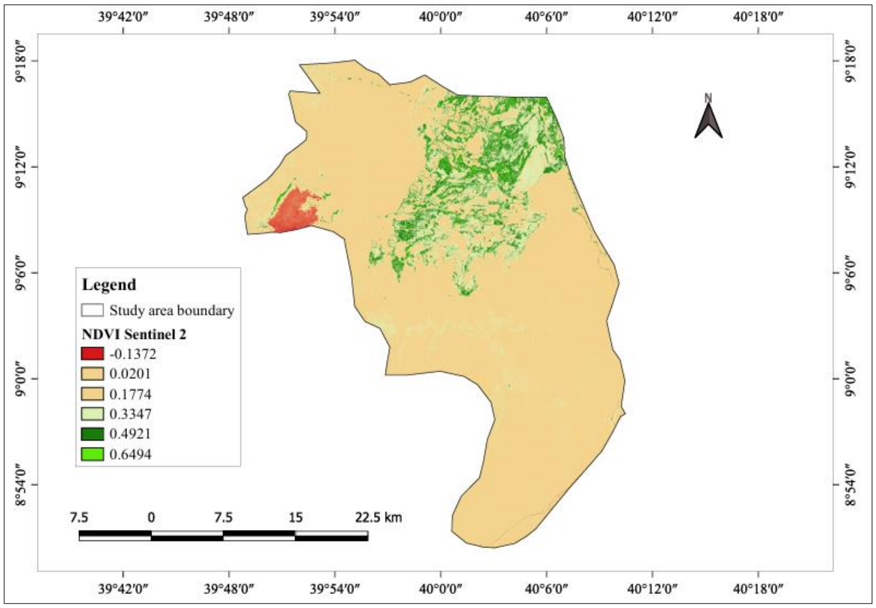


Figure 4. 10: Mean NDVI of Sentinel-2 image for only 2023 time period.

The contribution of the invasive species Prosopis juliflora to the observed greenness, as shown in the TCC and FCC of Figures 4.1 and 4.2 for Sentinel 2, is particularly evident when considering the NDVI in Figures 4.8 and 4.9.

4.5.Time Series Evaluation of the NDVI and Climatic Factors

Climate factors, particularly temperature and precipitation, play a critical role in influencing the growth and spread of invasive species. In the specified study area, characterized by an arid climate, vegetation growth primarily depends on the availability of rainfall and land surface temperature. Even slight spatiotemporal variations in vegetation are deemed significant. By conducting a statistical evaluation of Landsat OLI, ETM+, and ETM images over the past 30 years using the Google Earth Engine platform, the study revealed that vegetation thickness shows an increasing trend from 1993 to 2003 and again from 2013 to 2023 (Figure 4.11). However, vegetation thickness declined sharply from 2003 to 2013 compared to other periods.

This decline may be attributed to changes in climate patterns in the study area, such as decreased rainfall or increased temperatures during that time.

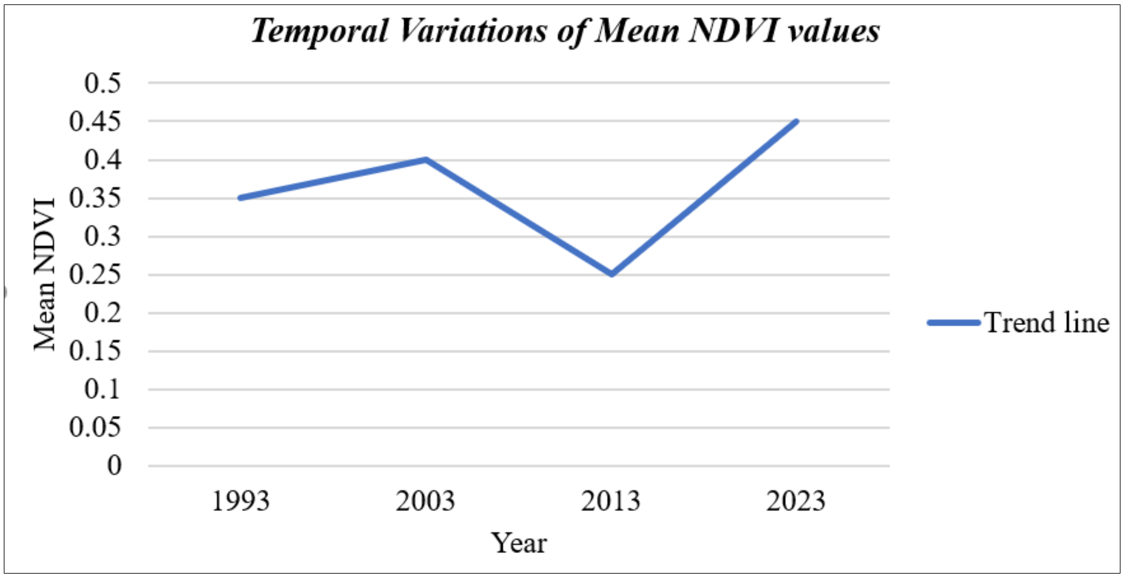


Figure 4. 11 : Temporal Variation of Mean NDVI Values at Four Time Points (1993, 2003, 2013, and 2023).

4.6.Prosopis juliflora Trend Analysis in Regression

The mean NDVI data for the entire time range was extracted simultaneously from Landsat 5, 7, and 8 at a 30 m resolution, obtained from ClimateEngine.org (**http://climateengine.org**, version 2.1) as referenced by Huntington et al. (2017). This data was used to conduct regression trend analysis. The results include the standardized coefficients of the mean NDVI and the regression of the mean NDVI by year (Table 4.3).

Table 4. 3 :Standardized coefficients (Mean_NDVI)

Regression Statistics	
Multiple R	0.660
R Square	0.435
Adjusted R Squar	0.416
Standard Error	0.030
Observations	31

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.0203	0.0203	22.3462	0.0001
Residual	29	0.0263	0.0009		
Total	30	0.0466			

	Coefficien	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-5.445	1.214	-4.484	0.000	-7.929	-2.962	-7.929	-2.962
Year	0.003	0.001	4.727	0.000	0.002	0.004	0.002	0.004

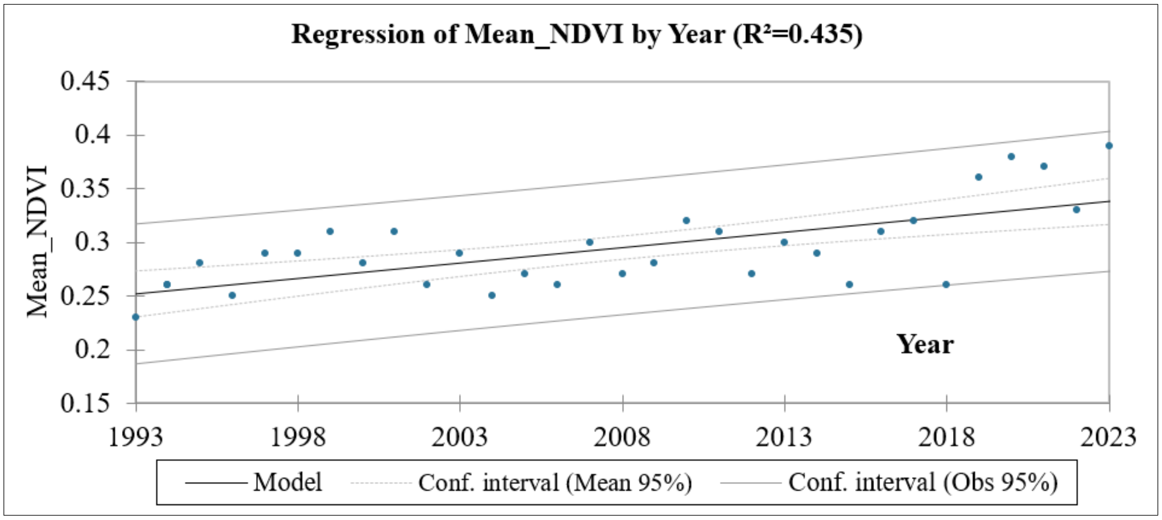


Figure 4. 12:Shows regression of mean NDVI by year.

The explanatory variable, time, accounts for 44% of the variability in the dependent variable, Mean_NDVI, as indicated by the R^2 value. The computed p-value from the ANOVA table (0.0001), with a significance level of 5%, demonstrates that the information provided by the explanatory variables significantly surpasses that of a basic mean. The model equation, Y = -5.44 + 0.003*Year reveals a positive slope, indicating an increase in vegetation thickness within the study area over the specified time range. This increase in NDVI is primarily attributed to the proliferation of Prosopis juliflora , which is the dominant factor among the identified land use and land cover types in the study area. Consequently, the observed rise in NDVI levels reflects the enhanced greenness associated with the invasion of this species.

4.7.The Mann-Kendall Trend Analysis

Table 4. 4: Mann-Kendall trend test / Two-tailed test (Mean_NDVI)

Kendall's tau	0.459
S	206
Var(S)	3417.333
p-value (Two-tailed)	0.000
alpha	0.05

Given the assumption:

H0: There is no trend in the series

Ha: There is a trend in the series

Based on the given statistical values(Table 4.4), the Kendall's tau coefficient is 0.459, with a p-value of 0.000. The significance level (alpha) is set at 0.05.

The Kendall's tau coefficient measures the strength and direction of the ordinal association between two variables. In this case, a coefficient of 0.459 suggests a moderate positive correlation between the variables. The p-value of 0.000 indicates that the observed correlation is statistically significant. A p-value less than the significance level (0.05) suggests that the correlation is unlikely to have occurred by chance alone. Therefore, as the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

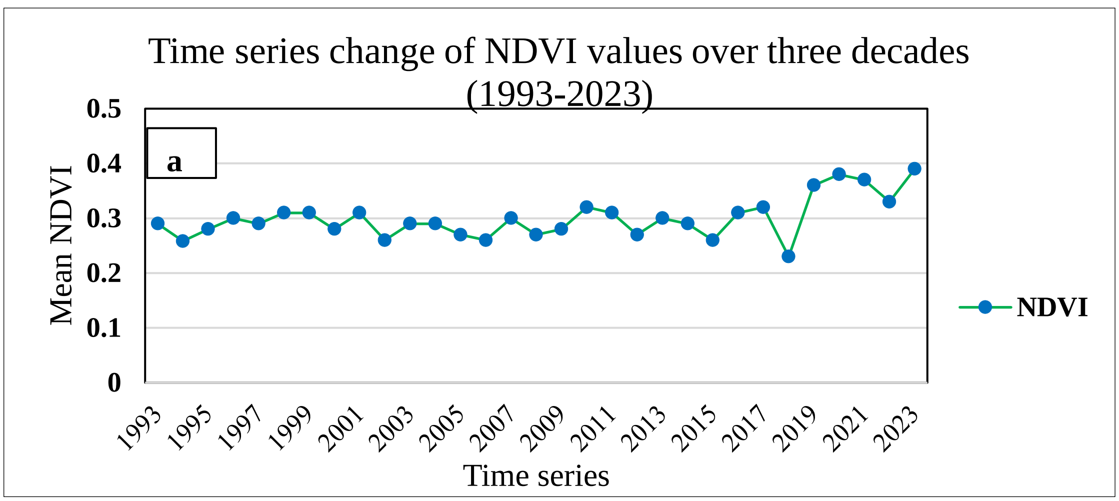


Figure 4. 13 :Vegetation trends from 1993 to 2023 in Awash Fentale District.

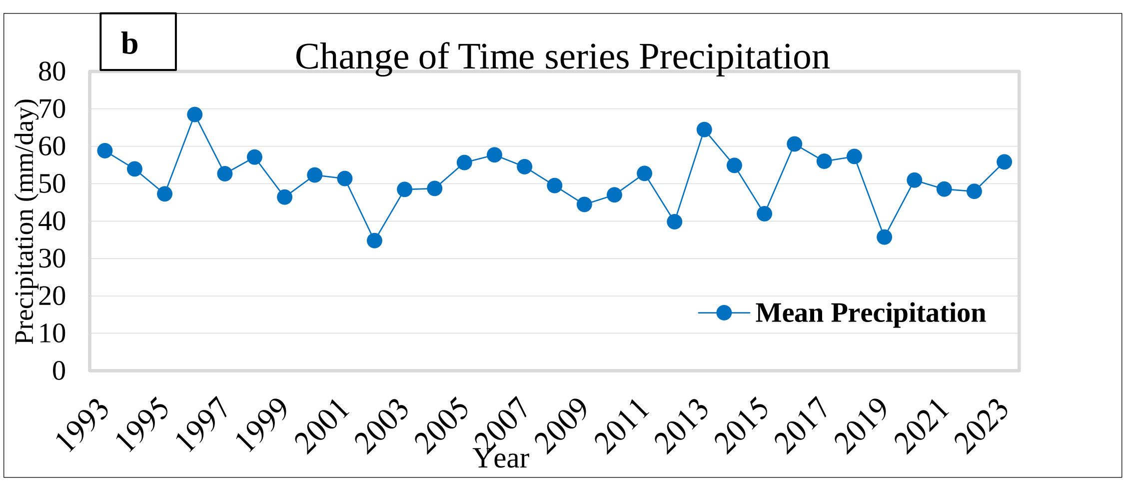


Figure 4. 14: Yearly average of precipitation from 1993 to 2023 in AF District.

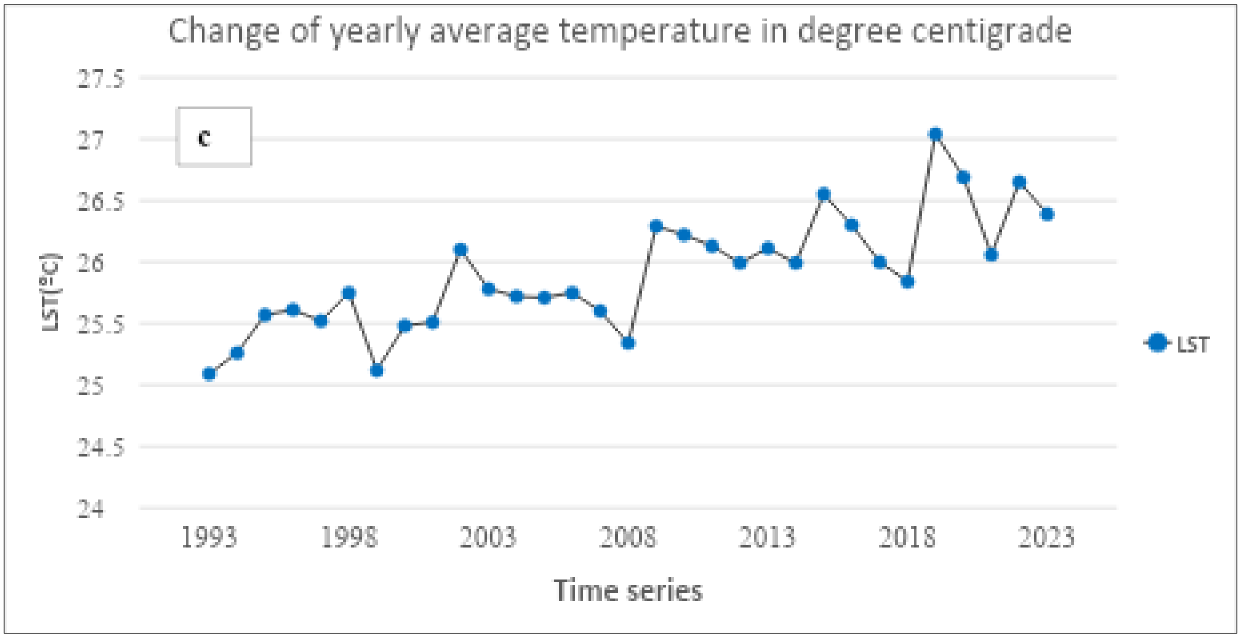


Figure 4. 15 :Yearly average LST from 1993 to 2023 in AF District.

The trend line extracted from TerraClimate of ClimateEngine.org, a collaborative initiative supported by Google and involving researchers and data scientists from the Desert Research Institute and the University of California Merced, shows the relationship between yearly mean NDVI, precipitation, and LST from 1993 to 2023. Figure 4.14(a), 4.15(b), and 4.16(c) display the trend line graph, highlighting the slight dependence of vegetation density on precipitation and temperature.

The time series graph indicates that in 1993, there was an increase in NDVI and precipitation, while LST displayed a decreasing trend. A similar pattern can be observed in 2003, but in 2013, a simultaneous decrease in temperature and precipitation was observed, while the trend line still indicated an increase in vegetation density. In 2023, a positive relationship between NDVI line and precipitation was observed once again, while an inverse relationship between NDVI and LST persisted.

This increasing trend in NDVI suggests that Prosopis juliflora is expanding throughout the study period, contributing significantly to the density of vegetation in the area. The time series graph strongly supports a direct relationship between vegetation greenness and precipitation, while highlighting an inverse relationship between NDVI and LST.

The mapping of LST and Precipitation allows for the identification of spatial and temporal variability in surface temperature and precipitation. By analyzing LST and precipitation patterns across different locations and time points, it is possible to observe variations in temperature and precipitation distribution and detect areas of interest for further investigation. Below, the map of LST and precipitation is displayed for the study area for target point time times 1993,2003,2013, and 2023 (Figure 4.17 and 4.18).

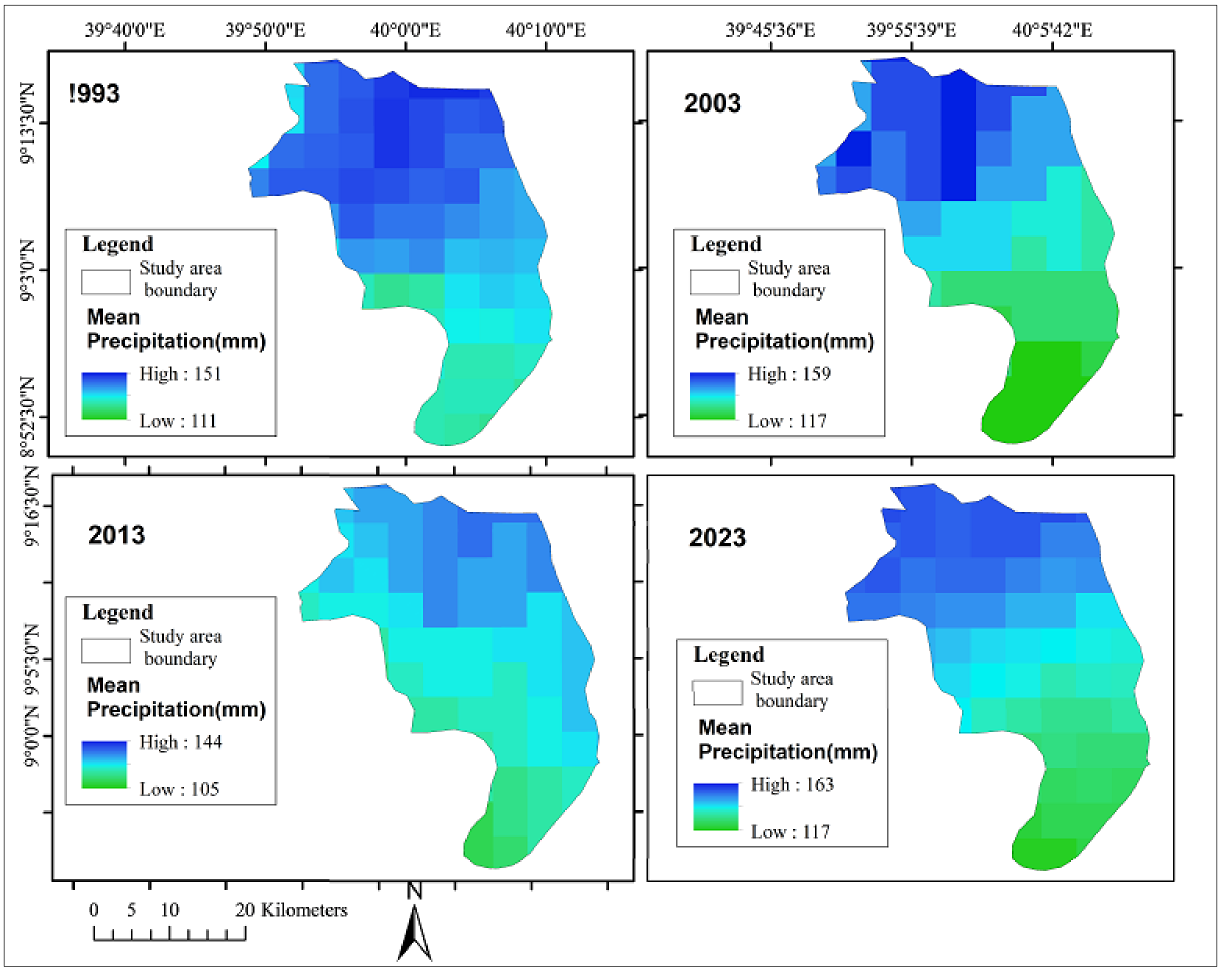


Figure 4. 16: Average sum of yearly precipitation.

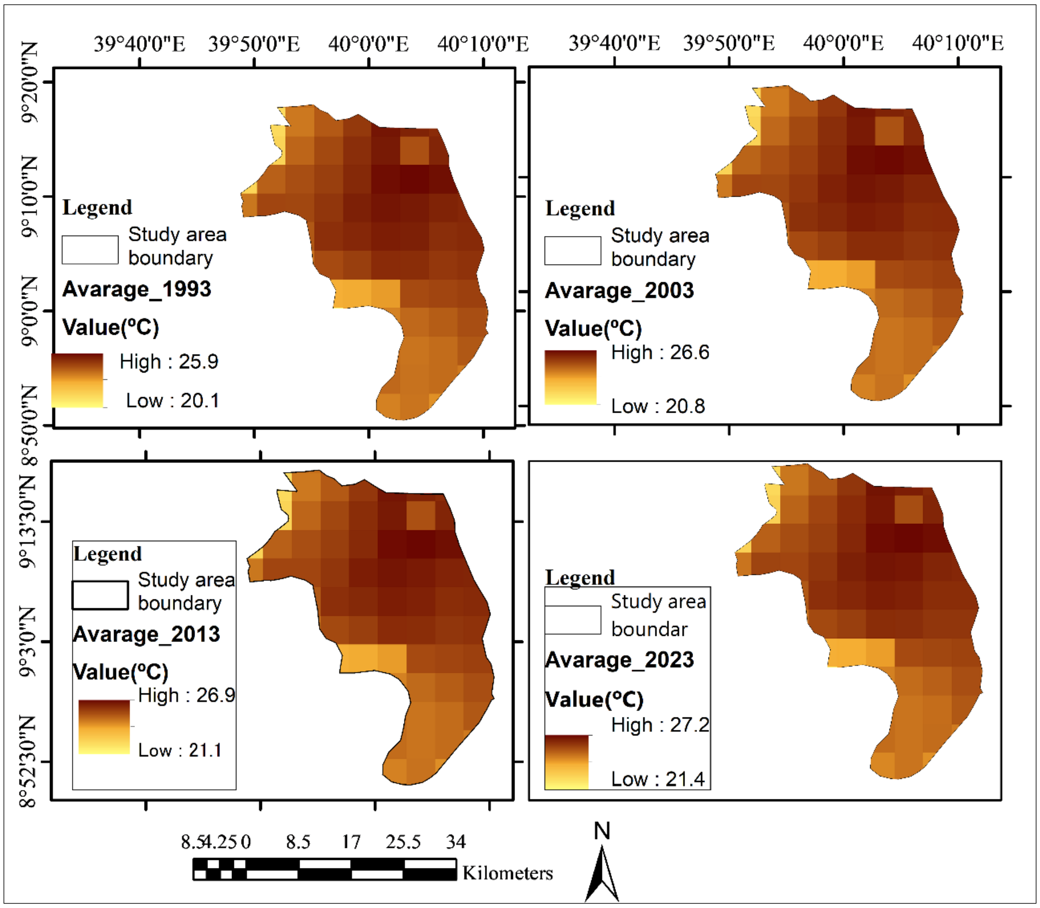


Figure 4. 17: Shows yearly LST mean for the years of 1993,2003,2013, and 2023.

Table 4. 5: Precipitation, LST, and NDVI mean values computed for the indicated time periods

Year	Mean Precipitation(mm)	NDVI	LST (°C)
1993	131	0.35	23.02
2003	138	0.41	23.71
2013	124	0.25	24.045
2023	140	0.45	23.53

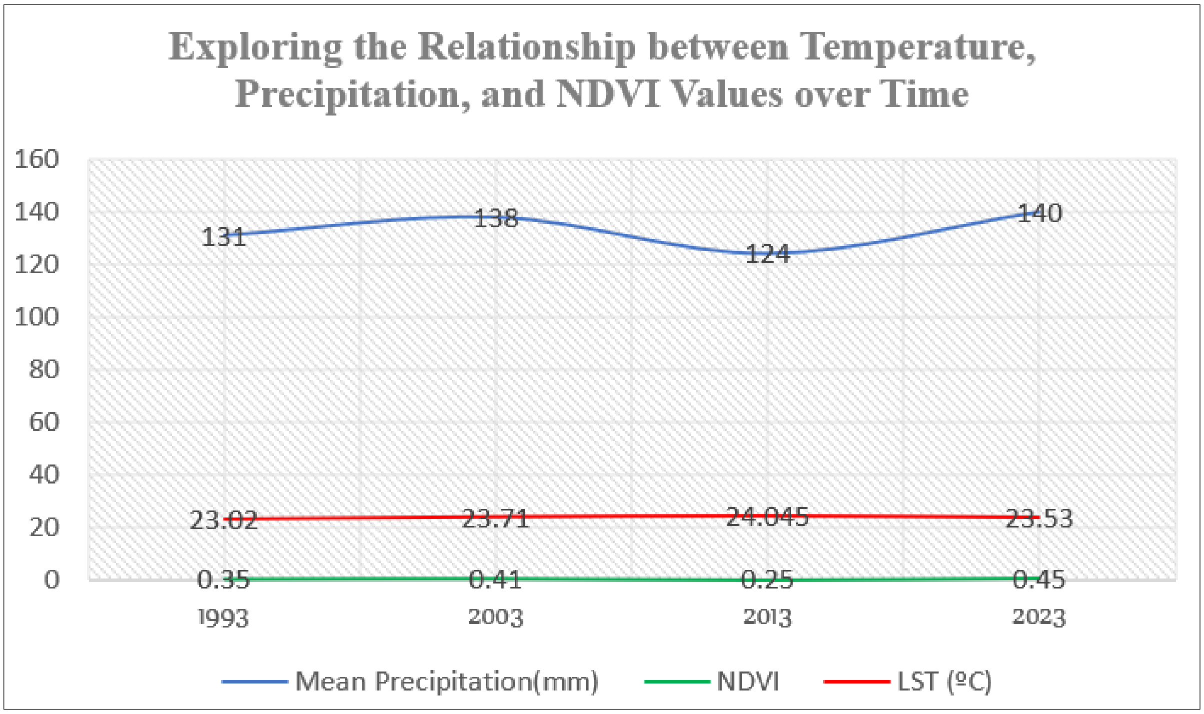


Figure 4. 18:Trend Analysis of Temperature, Precipitation, and NDVI Over Four Time Points (1993, 2003, 2013, and 2023).

Both table 4.5 and Figure 4.19 indicated that temperature values fluctuated over the years, exhibiting a slight increase from 1993 to 2013, followed by a decrease in 2023 (Figure 4.19). In contrast, precipitation values varied throughout the years, reaching their highest point in 2023 and their lowest in 2013. Additionally, the NDVI values remained relatively stable from 1993 to 2003, with a significant increase observed from 2013 to 2023.

In another way, in 1993, the precipitation value was 131, and the corresponding NDVI value was 0.35. By 2003, the precipitation value had risen to 138, while the NDVI value showed a slight increase to 0.41. In 2013, the precipitation value decreased to 124, accompanied by a drop in the NDVI to 0.25. Finally, in 2023, the precipitation value increased again to 140, and the NDVI value saw a notable rise to 0.45. These trends suggest that higher precipitation levels in 2003 and 2023 corresponded with higher NDVI values, indicating a positive relationship between precipitation and vegetation vigor. The study by Hao et al.,(2012) on Vegetation NDVI linked to temperature and precipitation in the upper catchments of Yellow River reported that annual precipitation rose from 301.8 mm in 2000 to 426.0 mm in 2006, which corresponded with an increase in the NDVI value of grassland from 0.307 to 0.345. Furthermore, the NDVI value of forested areas also showed a notable increase, reaching 0.463 during the same period. These results underscore the conclusion that increased precipitation is positively associated with enhanced vegetation vigor, as indicated by elevated NDVI values.

The line graph for LST displays a trend of fluctuating values, starting at 23.02°C in 1993, increasing to 23.71°C in 2003, and peaking at 23.53°C in 2023. Meanwhile, the NDVI line graph reflects a relatively stable trend, beginning at 0.35 in 1993, rising to 0.41 in 2003, slightly decreasing to 0.25 in 2013, and then increasing again to 0.45 in 2023. While the research conducted by Wakie et al. (2014) indicated a correlation between the expansion of Prosopis juliflora and temperature, this study reveals a variable relationship between the NDVI and LST. Narrating this relationship helps in identifying trends and patterns over time, which can inform policymakers and stakeholders about the ecological consequences of climate change.

4.8. Regression analysis to determine the impacts of climatic on NDVI

To determine the impact of precipitation and temperature on vegetation density and expansion in the study area, a regression analysis was performed. Table 4.6 presents the mean values of NDVI, precipitation, and temperature data collected from representative sample points for the period 1993–2023 from Climaticengine.org. These variables were used to perform a regression analysis to evaluate the relationships between climatic factors, precipitation and temperature, and NDVI. The analysis specifically focused on identifying the dominant predictors, precipitation and temperature, with Prosopis juliflora being the species that invades the study area.

Table 4. 6: Mean NDVI, Precipitation, and Temperature Data for Regression Analysis

SNo	NDVI Mean	Mean monthly Temperature	Tota average Precipitation	SNo	NDVI Mean	Mean monthly Temperature	Tota average Precipitation
0	-0.21	27.11	500.00	25	0.28	26.85	579.10
1	0.32	26.59	603.50	26	0.31	26.29	631.20
2	0.31	26.45	609.90	27	0.27	26.71	591.00
3	0.30	26.44	618.40	28	0.44	26.81	587.20
4	0.25	26.14	631.20	29	0.28	26.47	610.90
5	0.23	26.82	600.90	30	0.17	26.13	600.90
6	0.27	26.04	639.40	31	0.62	25.18	578.90

7	0.18	26.75	589.30	32	0.45	26.01	573.90
8	0.34	25.65	678.10	33	0.56	25.99	689.50
9	0.66	25.92	693.10	34	0.27	26.66	602.30
10	0.25	26.25	655.50	35	0.33	26.38	620.70
11	0.55	26.07	573.80	36	0.20	26.83	582.90
12	0.38	26.95	573.60	37	0.22	26.04	639.40
13	0.13	26.55	550.10	38	0.21	26.45	609.90
14	0.43	26.54	578.10	39	0.29	26.55	602.90
15	0.32	26.08	625.70	40	0.37	25.44	697.80
16	0.40	26.64	719.00	41	0.22	26.82	582.00
17	0.70	25.99	721.60	42	0.74	25.50	720.30
18	0.31	25.92	670.30	43	0.25	26.45	624.90
19	0.73	25.50	721.30	44	0.49	26.12	719.60
20	0.31	26.35	616.80	45	0.23	26.16	638.60
21	0.24	26.14	618.70	46	0.31	26.17	630.30
22	0.65	26.12	672.50	47	0.20	26.90	574.00
23	0.23	26.90	574.00	48	0.37	26.64	622.60
24	0.32	26.76	603.20	49	0.55	26.00	573.80

Table 4. 7 :Regression of climatic variables with mean NDVI

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.683
R Square	0.466
Adjusted R Square	0.443
Standard Error	0.130
Observations	50.000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2.000	0.699	0.349	20.523	0.000
Residual	47.000	0.800	0.017		
Total	49.000	1.499			

	Coefficients	*ndard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	3.841	1.613	2.381	0.021	0.595	7.087	0.595	7.087
Mean_preci_2014_2023	0.001	0.000	2.681	0.010	0.000	0.002	0.000	0.002
Mean_To_2014_2023	-0.162	0.054	-3.011	0.004	-0.271	-0.054	-0.271	-0.054

The multiple R value of 0.683 on table 4.7 indicates a moderate positive correlation between the climatic factors and NDVI. This suggests that there is a relationship between the climatic conditions and the vegetation index in the study area. The R square value of 0.466 indicates that approximately 46.6% of the variation in the NDVI can be explained by the climatic factors. This implies that the climatic conditions have a significant influence on the vegetation index.

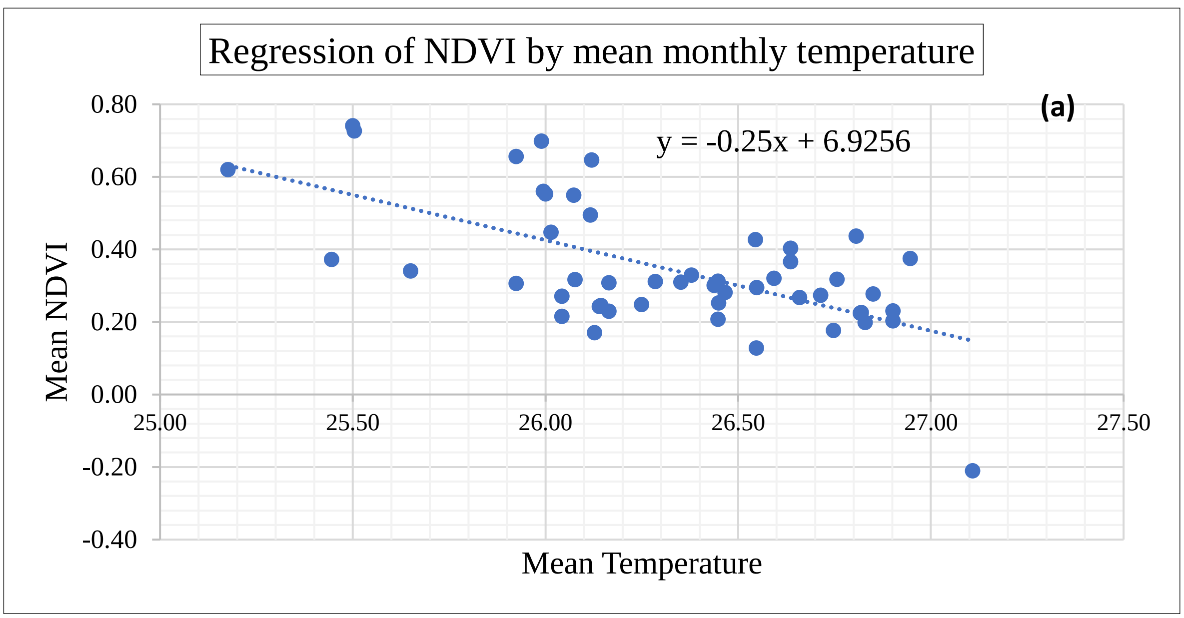
The significance F value of 0.000 indicates that the overall regression model is statistically significant. This means that the relationship between the climatic factors and the NDVI is unlikely to have occurred by chance alone. The p-value associated with the F test is below the significance level of 0.05, providing strong evidence of a significant relationship.

Considering these statistical values, we can conclude that the climatic factors have a significant impact on the NDVI of the study area. The moderate positive correlation, along with the substantial proportion of variation explained by the climatic factors, suggests that changes in the climatic conditions can influence the vegetation dynamics and productivity in the study area.

The model can be computed as the equation:

Estimated NDVI = Constant + coef_LST(LST) +coefPrecip(P) + residual

Estimated NDVI = 3.84-0.162(LST) +0.001(P) + 47



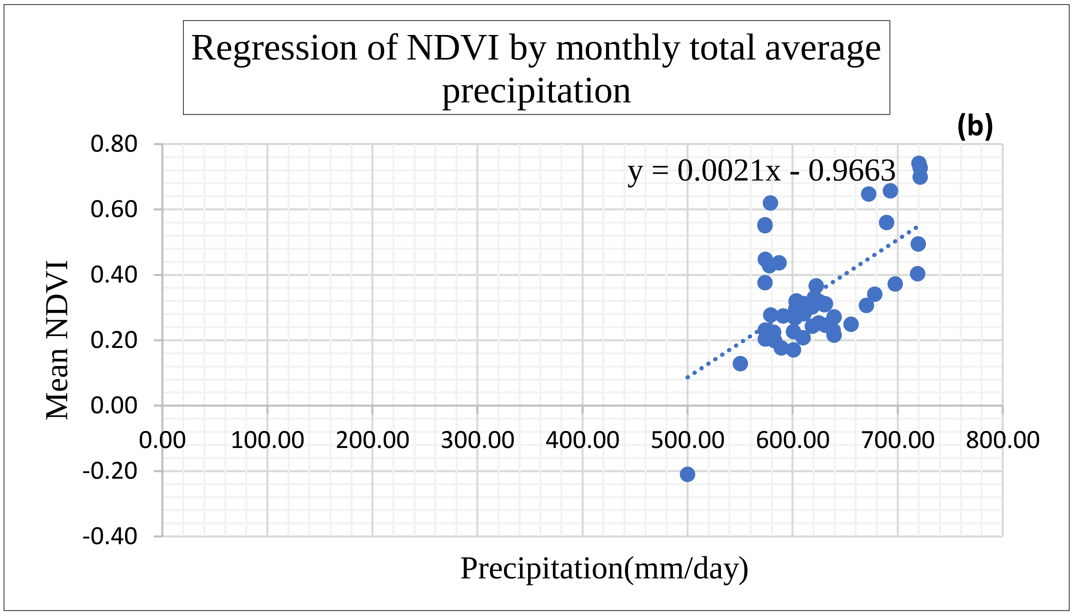


Figure 4. 19: Regression analysis of two climatic factors, Temperature (a) and Precipitation(b), against the mean NDVI value. The figure visually depicts the relationship between these climatic factors and the vegetation health represented by the mean NDVI value.

4.9.The livelihood impacts of Prosopis juliflora

4.3.1. Household characteristics

To assess the livelihood impact of Prosopis juliflora in the study area, data was collected from household heads in two kebeles called Didub and Kebena. The gender breakdown of the participants revealed that 31% of the respondents from Didub were female, while 69% were male(Table 4.8). In Kebena (Table 4.9), the gender distribution was slightly different, with 34% female and 66% male participants. This indicates a predominance of male respondents across both kebeles, reflecting potential gender dynamics in agricultural practices or resource management.

The age distribution of the surveyed population highlighted that the majority of participants (40% in Didub and 57% in Kebena) fell within the age group of 31-40 years. This suggests that individuals in this age range are likely to be more engaged in socio-economic activities related to Prosopis juliflora, possibly due to their established roles in household decision-making and resource utilization. Conversely, only 6% in Didub and 8.6% in Kebena of the surveyed population belonged to the older age group of 50-70 years, indicating a potential gap in participation among older individuals which could be influenced by factors such as health or and mobility.

Table 4. 8: Demographic and occupational statistics of Didub kebele household respondents.

Age Group	Sex				Occupation					
	Male	Female	Total	%	Pastoral	Agro-Pastoral	Trade	Others	Total	%
18-30	5	3	8	23	3	3	1	1	8	23
31-40	8	6	14	40	9	3	1	1	14	40
41-50	9	2	11	31	4	1	3	3	11	31
51-70	2	0	2	6	2	0			2	6
Total	24	11	35	100	24(68.8)	7(20)	2(5.7)	2(5.7)	35	100

Table 4. 9 :Demographic and occupational statistics of Kebena kebele household respondents

Age Group	Sex				Occupation					
	Male	Female	Total	%	Pastoral	Agro-Pastoral	Trade	Others	Total	%
18-30	7	1	8	23	2	2	2	2	8	20
31-40	8	6	14	40	9	3	1	1	14	57
41-50	6	5	11	31	4	1	3	3	11	14.4
51-70	2	0	2	6	1	1			2	8.6
Total	23	12	35	100	24(68.8)	7(20)	2(5.7)	2(5.7)	35	100

In the intentionally selected two kebeles, 68.8% of respondents identified pastoralism as their primary occupation, while 20% engaged in agro-pastoralism. The remaining 5% of respondents were involved in trade and other occupations, respectively(Table 4.7 and Table 4.8).

4.3.2. Distribution patterns of Prosopis juliflora

During KII conducting with District's natural resource management experts in the study area, they expressed uncertainty regarding the origins of Prosopis juliflora. However, based on subjective evidence, it was hypothesized that the invasive plant was introduced by the French at Melka Worer Agricultural Resource during the Derg regime. Particularly, 89% of respondents from Kebena and 63% from Didub identified this hypothesis (Tables 4.10 and 4.11). The main drivers of this introduction was environmental including the need of reestablishing degraded areas, rejuvenation of bare lands, and sheds in homesteads. Conversely, 11% of Kebena respondents and 37% from Didub reported a lack of knowledge about the introduction of the species. The higher percentage of uncertainty in Didub can be attributed to the relatively low spread (as compared to Kebena) of Prosopis juliflora in that kebele, resulting in less direct experience with the plant among the households surveyed.

In Kebena, where Prosopis juliflora has proliferated due to favorable conditions, such as riverbanks, respondents demonstrated a deeper understanding of the plant's impacts on their livelihoods. The extensive spread of Prosopis juliflora in Kebena has been facilitated primarily through organic means, such as cow dung and goat droppings, leading to its pervasive presence in the environment. A study conducted by Shiferaw (2020) in the Afar National Regional State of Northeast Ethiopia revealed a significantly higher density of woody vegetation in the Kebena site compared to the adjacent Didub site.

Table 4. 10: Household perceptions regarding the introduction of Prosopis juliflora in Awash Fentale District, Didub site.

Agents		Frequency	Percent
Didub	Foreigners	22	63
	Don't know	13	37
	Total	35	100.0

Table 4. 11 : Household perceptions regarding the introduction of Prosopis juliflora in Awash Fentale District, Kebena site.

	Agents	Frequency	Percent
Kebena	Foreigners	31	88.6
	Don't know	4	11.4
	Total	35	100.0

4.3.3. Community's perception of livelihood impact and benefits of Prosopis juliflora

The awareness of the communities regarding the benefits and drawbacks of Prosopis juliflora in the Awash Fentale District was systematically evaluated through the implementation of precisely designed survey questionnaires (Table 4. 12). These criteria items were developed to facilitate a comprehensive understanding of the livelihood impacts and benefits associated with the spread of Prosopis juliflora within the community.

The plant's contribution as a fuel wood source is one of the main advantages that households in both Kebeles have highlighted; 51.42% of respondents in Didub and 42.85% in Kebena acknowledged the plant's significance for fuel(Table 4. 12). Charcoal making is another way that Prosopis juliflora generates revenue; 62.85% of respondents in Didub and a significant 74.28% in Kebena emphasized the plant's importance in sustaining the impoverished. Given that it offers a marketable product that helps economically disadvantaged groups, this income-generating potential is probably a key factor in acceptance or tolerance for the plant.

There is some practical value in providing building materials (Figure 4. 21), as seen by the tiny percentage of respondents (17.14% in Didub and 22.86% in Kebena) who mentioned the plant's usefulness for house construction. However, comparatively few respondents reported other potential benefits, indicating limited recognition of these roles. These benefits included increasing fodder availability (17.14% in Didub and 20% in Kebena), providing shade (2.86% in Didub and 5.71% in Kebena), mitigating climate change (5.71% in Didub and 2.86% in Kebena), and increase soil fertility 8.57 in Didub and null in Kebena kebele.

With unanimous or very unanimous responses in both Kebeles, the perceived disadvantages of Prosopis juliflora are overwhelming, notwithstanding its benefits. In both Didub and Kebena, all responders (100%) concurred that the species encroaches on grazing grounds, hinders human and livestock travel routes, and severely competes with native pasture. This suggests that traditional grazing methods and livestock and human mobility would be severely impacted, which will probably cause disruptions to daily routines and financial losses in the animal husbandry industry.

With 100% in Didub and 94.28% in Kebena, a significant portion of respondents also mentioned Prosopis juliflora-related health difficulties in cattle, which may be a sign of toxicity or physical harm from the plant's thorns. Prosopis juliflora frequently supplants other vegetation (reported by 94.28% in Didub and 82.85% in Kebena), which further reduces plant diversity. This invasive plant's dominance over other species has an adverse effect on biodiversity.

Water shortage and the drying of water sources are caused by Prosopis juliflora's invasive occupation of agricultural areas (94.28% in Didub and 85.71% in Kebena) and encroachment on waterways (97.14% in Didub and 82.85% in Kebena). The sustainability of agricultural and pastoral practices in these Kebeles is seriously threatened by this aggressive expansion, which affects crop cultivation as well as water supplies.

Overall, communities are mostly concerned about the negative consequences of Prosopis juliflora, even if it has certain ecological and economic benefits, mainly as a source of firewood and charcoal. The five-point Likert scale results show about 93% of the respondents have negative perception whereas 7% of households view Prosopis juliflora positively(Annex 3). Because of its invasiveness, the plant damages traditional land use, lowers biodiversity, blocks paths, and endangers the health of animals and water sources.

In a related study conducted by Seid et al. (2020) in the Amibara District of the Afar National Regional State, Ethiopia, it was reported that 90% of respondents had a negative perception of this species, with approximately 1% expressing a positive view and the remaining 9% being indifferent. The observed differences in perceptions between the two districts may be attributed to the fact that many communities in Awash Fentale, particularly in Kebena Kebele, have adapted to the presence of Prosopis juliflora and identified beneficial uses for it, notably in charcoal production.

Table 4. 12 Household opinions on the benefits and drawbacks of Prosopis juliflora in Awash Fenatle's Didub and Kebena Kebeles.

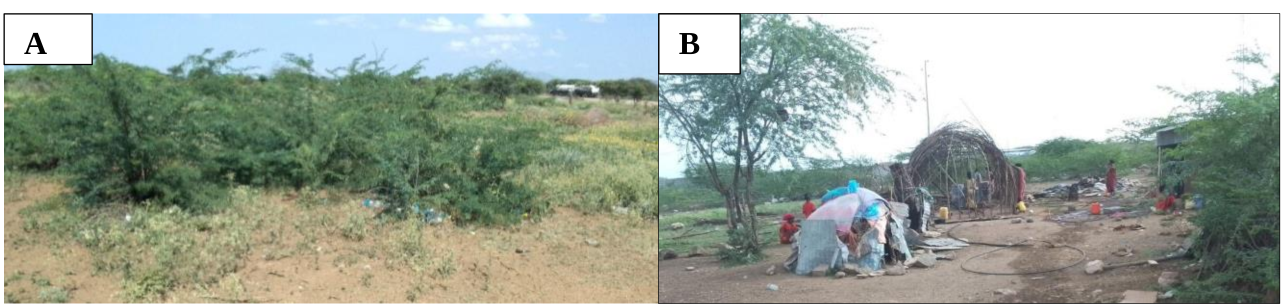
Benefit	Didub		Kebena	
	Frequency	%	Frequency	%
Increase fodder availability	6	17.14	7	20
Increase fuel wood availability	18	51.42	15	42.85
Mitigate the impacts of climate	2	5.71	1	2.86
Help increase soil fertility	3	8.77	0	0
Serve as a shade	1	2.86	2	5.71
Source of income for the poor (Charcoal)	22	62.85	26	74.28
Used for house construction	6	17.14	8	22.86
Impacts				

Competes with native pasture	35	100	35	100
Causes health issues in livestock	35	100	33	94.28
Reduction in plant diversity	35	100	30	85.71
Dominance over other plant species	33	94.28	29	82.85
Injuries to animals	34	97.14	30	85.71
Invasion of agricultural lands	33	94.28	30	85.71
Encroachment on grazing areas	35	100	30	85.71
Obstruction of livestock pathways	35	100	35	100
Obstruction of human pathways	35	100	35	100
Invasion of waterways and drying of water sources	34	97.14	29	82.85

Source: Owen survey, 2024

The map(4.21, A) illustrating the encroachment of Prosopis juliflora on grazing lands highlights one of the critical negative impacts of this invasive species in the study area. The expansion of Prosopis juliflora has led to reduction of grazing land. Its aggressive colonization limits the availability of vital rangelands, crucial for the pastoral livelihoods of the community, which depend on grazing animals for sustenance. The map also shows that its encroachment coincides with increasingly arid conditions, exacerbating land degradation. This could result from its deep root system, which depletes groundwater, reducing soil moisture and vegetation growth.

On the other hand, the map(4.21, B) demonstrates the utilization of Prosopis juliflora plantations for hut construction, reflecting its economic and practical value to local communities. The strong wood of Prosopis juliflora is durable and widely used for building huts, fences, and other structures. In resource-scarce environments, this provides an affordable and accessible material. Though not shown explicitly on the map, Prosopis juliflora is often used for fuelwood and charcoal production, providing an alternative income source for rural households.



Source: Photo by the researcher, May 2024.

Figure 4. 20:Encroachment of Prosopis juliflora on grazing and agricultural lands(**A**) and pastoralists utilizing Prosopis juliflora plantation to construct their huts(**B**).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This study offers an in-depth analysis of the spatio-temporal dynamics of Prosopis juliflora in the Awash Fentale District, highlighting its profound ecological and socio-economic implications. By employing advanced remote sensing technologies, including Landsat imagery and Sentinel-2 data, and leveraging the capabilities of the Google Earth Engine (GEE) platform, the research explored the trends and impacts of this invasive species over a 30-year period (1993–2023). The findings illuminate the scale of the problem and identify key factors driving the rapid expansion of Prosopis juliflora, which continues to present critical challenges for the district's ecosystems and livelihoods.

The study documents a significant expansion of Prosopis juliflora, with its coverage increasing from 63 km^2 in 1993 to 87.3 km^2 in 2023. This 38% growth underscores the invasive species' remarkable adaptability and capacity to exploit diverse environmental conditions. Temporal analysis revealed an accelerated rate of spread over the past three decades, fueled by both natural and human-induced factors. Natural drivers include the species' ability to thrive in arid and semi-arid environments, with deep root systems that allow it to extract water from underground sources. Additionally, its capacity to fix nitrogen enables it to colonize nutrient-poor soils, outcompeting native vegetation.

Human activities such as overgrazing, land-use changes, and inadequate management practices have exacerbated the invasion. Overgrazing by livestock has created open patches of land, providing Prosopis juliflora with ideal conditions for propagation. Similarly, agricultural expansion and infrastructure development have disturbed natural ecosystems, enabling the species to establish itself in new areas. These findings emphasize the need for united effort of all stakeholders to prevent further spread.

The integration of Landsat and Sentinel-2 data with the GEE platform proved invaluable for mapping and monitoring Prosopis juliflora. The study highlights the efficiency of GEE in processing large datasets and conducting detailed spatio-temporal analyses. Sentinel-2 data, with its higher spatial and temporal resolution, demonstrated superior classification accuracy (97%) compared to Landsat 8 (90%), underscoring its potential as a reliable tool for future ecological studies. The ability to generate precise maps of invasion hotspots allows for targeted interventions, optimizing resource allocation and management efforts.

The research also showcases the broader applicability of remote sensing technologies in ecological studies, particularly in monitoring invasive species. By employing innovative tools and methodologies, this study sets a precedent for other regions facing similar challenges, providing a replicable framework for tracking and mitigating invasive species.

The encroachment of Prosopis juliflora has had severe consequence for pastoral communities in the Awash Fentale District. Its's spread into grazing lands has diminished the availability of pasture, jeopardizing the primary livelihood of the region's inhabitants. Livestock, a cornerstone of the local economy and culture, has been directly affected by the reduction in grazing resources, leading to decreased productivity and income. The species also obstructs access to water sources, further straining an already water-scarce environment. These challenges have compounded the vulnerability of pastoral communities, forcing many to adapt their traditional practices or seek alternative livelihoods.

The study's household survey revealed that 93% of respondents view Prosopis juliflora as detrimental, citing its negative impacts on grazing, agriculture, and water access. A small minority (7%) acknowledged potential economic benefits, such as its use for firewood and charcoal production. However, these benefits are minimal compared to the widespread ecological and economic damage caused by the species.

In addition to its socio-economic impacts, Prosopis juliflora has significantly disrupted the region's ecological balance. By displacing native vegetation, it has reduced biodiversity and altered habitat structures, negatively affecting flora and fauna that depend on indigenous ecosystems. This ecological degradation has ripple effects, diminishing the resilience of local ecosystems to withstand environmental stressors, including climate change. The transformation of landscapes, from diverse ecosystems to dense thickets of Prosopis juliflora, further exacerbates these challenges, making restoration efforts more complex.

The findings of this study underscore the urgent need for coordinated efforts to manage and mitigate the impacts of Prosopis juliflora. Addressing this challenge requires a multi-faceted approach that combines scientific research, policy interventions, and community engagement. The spatial data generated in this study provide a valuable resource for policymakers to prioritize intervention areas and design targeted strategies. Moreover, the strong correlation between climatic variables and the species' spread highlights the importance of integrating climate-resilient measures into management plans. Community involvement is critical to the success of management efforts. Engaging local populations in the control and utilization of Prosopis juliflora can help mitigate its negative impacts while unlocking potential benefits.

In conclusion, the spatio-temporal dynamics of Prosopis juliflora in the Awash Fentale District illustrate the complex interplay of ecological and socio-economic factors driving the spread of invasive species. The findings of this research provide a robust foundation for addressing the challenges posed by Prosopis juliflora, offering actionable insights for policymakers, researchers, and local communities. While the species represents a formidable challenge, the integration of advanced technologies, informed strategies, and active stakeholder participation offers a pathway to effective management and mitigation. This study serves as a model for tackling invasive species in other regions, emphasizing the critical role of technology, policy, and community collaboration in fostering sustainable ecological and socio-economic outcomes.

5.2.Recommendation

We offer the following suggestions for the sustainable management and control of Prosopis in the Awash Fental District, Afar region, Ethiopia, in light of our findings. By putting these suggestions into practice, management initiatives will be more successful and impacted communities' resilience will be strengthened.

- As understanding it is crucial for effective management strategies, all level government bodies should recognize the value of geospatial techniques for mapping the distribution of Prosopis juliflora.

- Though research organizations need to be encouraged to utilize high-resolution satellite imagery, such as Sentinel-2 and Landsat, to monitor changes in vegetation and assess the spatio-temporal dynamics of Prosopis juliflora, they should explore commercial satellite data to enhance the precision of invasive species mapping and thereby improving the quality of their analyses.
- Local development agencies and community-based organizations working in the area, need design programs that empower communities to utilize Prosopis juliflora sustainably, such as producing biochar, fuelwood, or crafts, thereby creating alternative income sources.
- Government bodies need to implement programs aimed at diversifying income sources for communities affected by Prosopis juliflora, including initiatives that promote the use of its wood for fuel or crafting.
- Awareness campaigns should be conducted to educate local communities about the negative impacts of Prosopis juliflora and effective management practices, fostering community engagement in control efforts.
- Further studies need to be conducted in other regions of Ethiopia to gain a comprehensive understanding of the national impact of Prosopis juliflora on livelihoods and ecosystems.
- Long-term research should focus on assessing the ecological and socio-economic impacts of Prosopis juliflora on biodiversity and local livelihoods, providing data to inform management strategies.
- Local administrative bodies should be strengthened to implement effective invasive species management strategies, ensuring that they have the necessary resources and training.
- Stakeholders from agriculture, forestry, and environmental sectors should collaborate to address the challenges posed by Prosopis juliflora, fostering a multidisciplinary approach to management.
- The effectiveness of community-driven interventions in controlling the spread of Prosopis juliflora should be evaluated, providing insights into best practices for local management.
- Research institutions should be tasked with developing models that simulate the growth patterns and ecological impacts of Prosopis juliflora, aiding in the identification of high-risk areas for targeted interventions.

- These models should be utilized to prioritize interventions based on risk assessments, ensuring that resources are allocated effectively.
- Dedicated units should be established to oversee and monitor interventions at the local level, ensuring accountability and continuous improvement in management practices.

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Annex 1:Survey Questionnaires Checklist to study Spatio-temporal trends of Prosopis juliflora plantation and its implications on livelihoods in Awash Fentale District, Afar regional state, Ethiopia

College of Social Science Addis Ababa University in partial fulfillment of the requirements for the Degree of Masters of Arts in Geography (Specialization: GIS, Remote sensing and Digital Cartography).

Dear respondents,

I hereby request you to respond to this questionnaire freely and all the answers you provided will be kept confidentially and only be used for academic purpose of this thesis data collection and analysis of the Spatio-temporal trends of Prosopis juliflora plantation and its implication on livelihoods in Awash Fentale District, Afar regional state, Ethiopia.

Thank you for your time and interest in the survey;

Tesfaye Taye (Graduating candidate): mob. 0901135247; email:tesfayetaye54@gmail.com

Section A: Personal Information:

The name of village /town ________________ Social status (respondent's):_____________ __

Put this mark(X) in the space provided:

1. Gender : Male_____ Female _________
2. Age range (years): 18 – 30_____ 31 – 40_______ 41 – 50_____ above 50_________
3. Marital status: Single________ Married _______ Divorced___________
4. Education status: Illiterate ______ Diploma______ Degree _______Masters _____PhD_____ If any other ______
5. How many people live in your household?____________
6. Do you have access to basic services such as healthcare, education, and clean water in your area? Yes__________,no____________,some______________________________.
7. Are you a permanent resident or a migrant in the area? _____________________.

Section B: Livelihood activities

1. What is your main occupation: ____________________________________?
2. Are there employment opportunities in the area? ______________________________.
3. What is your primary source of income or livelihood activity? _____________________.

4. What is your approximate annual household income?____________________(ETB).
5. Do you engage in any secondary or supplementary livelihood activities? If yes, please specify____.
6. Are you involved in any agricultural activities? If yes, what crops do you cultivate or what livestock do you raise?____.
7. Are you engaged in pastoralism or livestock rearing? If yes, what types of livestock do you own or manage? (1) Goats______(2) Sheep________(3) Camels______(4) others______
8. What is the type of grazing used here? (1)Mobile grazing______(2)Stable grazing _______
9. Are you involved in any natural resource extraction activities, such as mining, or forestry?____
10. Do you own land or have access to land for agricultural or other purposes?___________
11. What crops do you grow? ______________________________.
12. Have there been any changes in your livelihood activities over the past few years? If yes, please describe:____
13. Are there any opportunities or potential for improvement in your livelihood activities?____
14. What are the main challenges you face in your livelihood activities? ____
15. Do you engage in seasonal migration for livelihood purposes? ____

Section C: Vegetation resources

1. Are there natural plants in the area? ___________________________________
2. What are the prevailing types?____
3. What are the prevailing types of herbs in the region? _______________________
4. What are the most important herbs for pastorals? ____________________________
5. Are there forests in the area? (1) Yes________ (2) No_______ (3) There are very little forest ______________ (4) It was removed ______________
6. Are there natural plants that have disappeared from the area? _________________
7. Mention natural plants that disappeared from the area? ________________________.

8. Are there natural plants that appeared in the area? ______________________________.

9. Mention natural plants that appeared in the area? ________________________________

10. Did you notice a change in the amount of rain? ______________________________

11. How would you describe this change? (1) An increase in the period of precipitation_____________ (2) A decrease in the period of precipitation_________(3) steady____________________________

12. What is the effect of this change? (1).Lack of water__________ (2) Crop Failure__________(3) Animal death __________(4) Lack of productivity______________

Section D: Perception on prosopis plantation

1. Are you aware of the presence of Prosopis plantation in your area?: Yes___________No_________________.
2. What do you think about the prosopis tree? (1)Very good _________ (2)Good ______ (3)Harmful plant _________ (4) I do not know ________________________
3. What is your positive view of the mesquite tree? _______________________________.
4. What is your negative view of the Mesquite tree? ___________________________________.
5. Have you utilized Prosopis for any purposes? fuel wood______ timber_____ fodder________medicinal uses_________others____________________________
6. Have there been any changes in employment opportunities in the area as a result of Prosopis plantation? Describe____.
7. In your opinion, does Prosopis plantation tend to reduce biodiversity in the area? Yes_____ no_____________ don't know_______________
8. How do you perceive the impact of Prosopis plantation on local livelihoods? positive____________,negative________________no impact_________________________.
9. Have you observed any changes in land use due to the presence of Prosopis plantation? Yes_______________no_________________
10. Has the presence of Prosopis plantation affected your access to resources such as grazing land or water? Yes/no___________________
11. What strategies have you employed to cope with the impact of Prosopis plantation on your livelihood?____.
12. How do you perceive the government's interventions and policies regarding Prosopis management?____

13. Are there any community initiatives or awareness programs related to Prosopis plantation in your area?____

14. Do you consider Prosopis as a valuable resource for your livelihood activities? If yes, how do you utilize it?____

15. How do you perceive the impact of Prosopis plantation on ecosystem services such as water availability, soil fertility, or biodiversity?______________________

16. What measures or interventions do you think could help mitigate the negative impact of Prosopis plantation on livelihoods?_________________________________

17. Are there any community-based coping strategies or initiatives that have been implemented to address the impact of Prosopis plantation on livelihoods?____

18. Have you engaged in any collaborative efforts or collective action with other individuals or communities to address the challenges posed by Prosopis plantation on livelihoods?____

19. In your opinion, how effective have the coping strategies been in minimizing the negative impact of Prosopis plantation on livelihoods?_______________________________

20. What are the main challenges or limitations faced in implementing coping strategies related to Prosopis plantation and livelihoods?___________________________

21. Are there any opportunities for collaboration or partnerships with other stakeholders (e.g., NGOs, private sector, academia) to enhance the effectiveness of interventions?____

22. Based on your experiences, what recommendations do you have for improving coping strategies and addressing the challenges posed by Prosopis plantation on livelihoods?____

Annex 2: Classification Accuracy Assessment of All Landsat Versions and Sentinel-2 Images

The Error Matrix obtained from the classification of test pixels in Landsat 5 (1993).

ConfusionMatrix:

```
List (6 elements)
0: [8,0,0,0,0,0]
1: [0,9,1,0,1,1]
2: [3,0,8,0,0,0]
3: [0,0,0,9,0,1]
4: [0,0,0,0,6,0]
5: [0,0,0,0,0,10]
```

Overall Accuracy:0.88

Producer's Accuracy:[[1],[0.75],[0.73],[0.9],[1],[1]]

User's Accuracy: [[0.72],[1],[89],[1],[86],[83]]

Kappa:0.85

The Error Matrix obtained from the classification of test pixels in Landsat 7 (2003).

```
ConfusionMatrix:
List (6 elements)
0: [9,0,2,0,0,0]
1: [0,13,0,0,0,2]
2: [1,0,9,0,0,0]
3: [0,1,0,7,0,0]
4: [0,1,0,0,5,0]
5: [0,0,0,2,0,10]
```

Overall Accuracy:0.85

Producer's Accuracy: [0.82],[0.87],[0.9],[0.88],[0.83],[0.83]

User's Accuracy: [0.9],[0.87],[0.87],[0.78],[1],[0.83]

Kappa:0.82

The Error Matrix obtained from the classification of test pixels in Landsat 7 (2013).

ConfusionMatrix:

List (6 elements)

```
0: [6,0,0,0,0,0]
1: [0,13,0,1,0,1]
2: [0,0,7,0,0,0]
3: [0,0,0,8,1,0]
4: [0,1,0,0,11,0]
5: [0,0,0,2,0,5]
```

Overall Accuracy: 0.89

Producer's Accuracy: [1],[0.87],[1],[0.89],[0.92],[0.71]

User's Accuracy: [1],[0.93],[1],[0.73],[0.92],[0.83]

KAPPA: 0.87

The Error Matrix obtained from the classification of test pixels in Landsat 8 (2023).

```
ConfusionMatrix:

List (6 elements)
0: [9,0,0,0,0,0]
1: [0,15,2,0,0,0]
2: [0,0,12,0,0,0]
3: [0,2,1,6,0,0]
4: [1,0,0,0,9,0]
5: [0,1,0,0,0,12]
```

Overall Accuracy:0.90

Producer's Accuracy: [1],[0.89],[1],[0.67],[0.9],[0.92],

User Accuracy: [0.9],[0.83],[0.8],[1],[1],[1],

Kappa:0.88

The Error Matrix obtained from the classification of test pixels in Sentinel 2 (2023)

```
ConfusionMatrix:
List (6 elements)
0: [8,1,0,0,0,0]
1: [0,7,0,0,0,0]
2: [0,0,10,0,0,0]
3: [0,0,0,17,0,0]
4: [0,0,0,0,11,0]
5: [0,0,0,0,1,7]
```

Overall Accuracy: 0.967

`Producer's Accuracy: [[0.89],[1],[1],[1],[1],[0.875]]`

`User's Accuracy: [[1,0.875,1,1,0.92,1]]`

`KAPPA: 0.960`

The land use classes given by the lists of the six elements(0-5) is both for Sentinel 2 and Landsat 8 and they are:

0= Prosopis, 1 = Non-prosopis(Bush and shrubs), 2= Water, 3 = cultivation, 4 = bare land, 5 = built-up.

Annex 3 :Classification Script for Google Earth Engine

1993= https://code.earthengine.google.com/fdc9aa53b2b7fe2aa3571e92ec267bc2

2003= https://code.earthengine.google.com/f2e8e492274d090bc45658c5f0ac7f75

2013= https://code.earthengine.google.com/238980cbed8b25209b758a2c6a1047c8

2023= https://code.earthengine.google.com/e4a8d1db5d2a96377cc4dc678878e094

2023(S2)= https://code.earthengine.google.com/081993906458d4344b6d3d8c41a67583

Annex 4 : Over all perception of the community about the benefit of Prosopis juliflora, in Awash Fental district.

Perception	Score Range	Percentage	Number of Respondents
Negative Perception	7 – 17	93%	32
Neutral Perception	18 – 24	0%	0
Positive Perception	25 – 35	7%	3
Total	—	100%	35