



**WATER HYACINTH PROLIFERATION AND MANAGEMENT PROSPECTS IN THE  
CENTRAL RIFT VALLEY SYSTEM OF ETHIOPIA**

**A Dissertation Submitted to Centre for Environment and Development, School of  
Development Studies**

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**Dissertation Presented in the Fulfillment of the Requirements for the Degree of Doctor of  
Philosophy in Development Studies (Environment and Development)**

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**Addis Ababa, Ethiopia**

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**May 2025**

**Addis Ababa University**  
**School of Graduate Studies**

**WATER HYACINTH PROLIFERATION AND MANAGEMENT PROSPECTS IN THE  
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**Assefa Gudina Muleta**

**A Dissertation Submitted to Centre for Environment and Development, School of  
Development Studies**

**Presented in the Fulfillment of the Requirements for the Degree of Doctor of Philosophy in  
Development Studies (Environment and Development)**

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**Addis Ababa University**

**Addis Ababa, Ethiopia**

**May 2025**

## Dissertation Approval

Addis Ababa University  
School of Graduate Studies

This is to certify that the thesis prepared by Assefa Gudina Muleta, entitled: WATER HYACINTH PROLIFERATION AND MANAGEMENT PROSPECTS IN THE CENTRAL RIFT VALLEY SYSTEM OF ETHIOPIA, submitted in the fulfillment of the requirements of the Degree of Doctor of Philosophy in Development Studies (Environment and Development) complies with the regulations of the university and meets the accepted standard.

With respect to originality and quality, signed by the examining committee:

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Advisor	Signature	Date
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Chairperson of Department or Graduate Program Coordinator

## Statement of Author

I, the undersigned, declare that this is my original work, has never been presented in this or any other university, and that all the resources and materials used for the dissertation, have been fully acknowledged.

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Signature \_\_\_\_\_

Date \_\_\_\_\_

Place \_\_\_\_\_

Date of Submission \_\_\_\_\_

This dissertation has been submitted for examination with my approval as the dissertation supervisor.

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## List of Acronyms and Abbreviations

ANN	Artificial Neural Networks
CNNs	Convolutional Neural Networks
CO <sub>2</sub>	Carbon Dioxide.
DEM	Digital Elevation Model
DID	Difference-in-Differences
DO	Dissolved Oxygen
ETM+	Enhanced Thematic Mapper Plus
FDRE	Federal Democratic Republic of Ethiopia
GEE	Google Earth Engine
GHGs	Greenhouse Gases.
GIS	Geographic Information System
IDRISI	Integrated Data Retrieval and Interpretation System for Imaging
LCM	Land Change Modeler
LULCC	<i>Land Use Land Cover Classification</i>
LULCC*	Land Use Land Cover Change
MLP	Multi-Layer Perceptron
NH <sub>3</sub> -N	Ammonia-Nitrogen
NO <sub>3</sub> --N	Nitrate-Nitrogen
NO <sub>3</sub> --N	Nitrate-Nitrogen
OLI	Operational Land Imager
PA	Producer Accuracy
PD	Population Density
PMS	Principal Mode Shaping
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
RFC	Random Forest Classification
SDG	Sustainable Development Goals
SPSS	Statistical Package for the Social Sciences
SRP-PO <sub>4</sub>	Soluble Reactive Phosphate
SVMs	Support Vector Machines
TLU	Tropical Livestock Unit
TN	Total Nitrogen
TP	Total Phosphorus
UA	User's Accuracy
UNEP	United Nations Environment Programme
USGS	United States Geological Survey
WLS	Weighted Least Squares
WTCL	Willingness To Contribute Labor

### **List of Publications**

- Gudina, A., Woldemedhin, D.G., Seyoum, A., Senbeta, F., Assefa, E., and Alemayehu, A. (2025). *Water hyacinth [Eichhornia Crassipes (Mart.)] invasion: implications for livelihoods in the central Rift Valley of Ethiopia*. *Front. Sustain. Food Syst.* 8:1490881
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- Gudina, A., Woldemedhin, D.G., Seyoum, A., Senbeta, F., Assefa, E. and Alemayehu, A. *Water Hyacinth Control and Management Strategy: The Prospects of Willingness to Contribute Household Labor* (under preparation for submission)
- Gudina, A., Woldemedhin, D.G., Seyoum, A., Senbeta, F., Assefa, E. and Alemayehu, A. *Water Hyacinth Management and Policy Implications in the Central Rift Valley of Ethiopia: Stakeholders, Institutions and Community Engagement* (under preparation for submission)
- Gudina, A., Woldemedhin, D.G., Seyoum, A., Senbeta, F., Assefa, E. and Alemayehu, A. *Environmental Impacts of Water Hyacinth Proliferation in the Rift Valley Lakes of Ethiopia: The Case of Koka and Dembel* (under preparation for submission)

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## General Abstract

*Water hyacinth, an invasive aquatic weed, poses significant challenges to aquatic ecosystems globally. Since the early 1950s, the plants have been expanding aggressively and affecting the natural ecosystems and livelihoods of the community in the Central Rift Valley of Ethiopia. The infestation of weeds has been substantially exacerbated by the excessive nutrient loading from the surrounding farmlands into the lake system, particularly nitrogen and phosphorus. This study explores the trends of water hyacinth infestations in Koka and Dembel lakes in the Central Rift Valley of Ethiopia. The study explored the interface between land use/land cover changes (LULCC) and the proliferation of water hyacinth, its impacts on the environment and livelihood, and management frameworks. Data was gathered from 348 households, six focus group discussions, and interviews with 6 key informants from diverse groups. Propensity Scores, Difference-in-Differences, and Weighted Least Squares methods were applied to evaluate the effects of the plants on livelihoods and ecosystem services. Field observations and satellite imagery were also utilized to assess LULCC and water hyacinth spread. To evaluate the impact of the plant on water quality, twenty-four water samples were collected using pre-cleaned polyethylene bottles. Following the standard procedures of water lab analysis, water parameters such as PH, Dissolved Oxygen (DO), Temperature, Total Nitrogen (TN) and Nitrate-Nitrogen (NO<sub>3</sub>-N), Ammonia-Nitrogen (NH<sub>3</sub>-N), Total Phosphorus (TP) and Soluble Reactive Phosphate (SRP-PO<sub>4</sub>), Sulphate and Sulfide and salinity were also analyzed. The study revealed that water hyacinth's adverse effects outweigh its benefits. In Lake Dembel, coverage increased from zero in 1994 to over 4,000 hectares by 2024, with a similar expansion in Koka Lake. LULCC due to agricultural expansion, urbanization, and deforestation contributed to increased nutrient runoff, promoting water hyacinth growth. This led to increased sedimentation and nutrient runoff into the lakes of Koka and Dembel which in turn promoted the growth and expansion of water hyacinth. The feedback loop between LULCC changes and water hyacinth proliferation is a complex, self-reinforcing cycle. Historical data underscore a significant rise in total phosphorus concentrations, particularly in Lake Koka, attributed to effluent discharge and agricultural runoff. Lake Dembel showed TN (0.47–7.86 mg/L) and TP (0.07–1.64 mg/L), with TP exceeding eutrophication thresholds. Lake Koka had higher pollution, with TN (0.83–8.96 mg/L) and TP (0.14–3.8 mg/L), particularly near agricultural inflows. The assessments indicate alarmingly high nutrient levels, with Lake Koka exhibiting higher pollution loads than Lake Dembel. The nutrient concentrations surpass eutrophication thresholds in both lakes, necessitating urgent management. The expansion of the plant is currently disrupting the hydrological system, affecting fishing and navigation, and leading to socio-economic losses for the local community. The result of Difference-in-Differences shows a decline in the total annual income by 823 ETB, income from crop production by 329 ETB per year, and income from off-farm activities by 6952 ETB per year for those living adjacent to the invaded lakes. Although the*

*impact varies according to the intensity of the water hyacinth infestation, it adversely affects rural livelihoods by reducing crop yields and returns from off-farm activities. The study results showed that 96 percent of the respondents are willing to participate in management practices through labor contribution. However, the willingness to contribute labor is affected by the initial and secondary bids, gender, lakes' water quality knowledge, livestock size, and educational status. Despite the existence of various comprehensive policies related to water hyacinth management, the study revealed that the practical implementation of these regulations is far from ideal, owing primarily to resource constraints, insufficient integration of policy measures, and a lack of robust enforcement mechanisms. Effective management requires integrated strategies addressing both land use practices and invasive species control. The study emphasizes the need for coordinated management efforts to restore the impacts of water hyacinth on the ecological and socio-economic value of Lakes Koka and Dembel. The study recommended effective management of water hyacinth in Lakes Koka and Dembel requires integrated strategies that address both land use practices and invasive species control, with a strong emphasis on policy enforcement, community involvement, and resource allocation to mitigate the ecological and socio-economic impacts of this invasive weed.*

**Keywords:** *Water Hyacinth, Environment, Ecology, Livelihood, Institutions, stakeholder, Rift Valley, Koka, Dembel.*

# Chapter 1: General Introduction

## 1.1 Background

Invasive species are inhabitants of water bodies as well as terrestrial which is not native to the area (Simberloff, 2015). These species include plants, animals, and microbes that primarily invade the area after human intrusions (Carroll, 2007). Though invasive species may provide various functions and services, they can also cause huge threats to native species and ecosystem services. Recently, the risk associated with invasive species have attracted global attention, allied to the impact on ecosystem goods and services, which would, in turn, impose an influence on human wellbeing and biodiversity loss (Keller et al., 2011; Rai and Singh, 2020). Water hyacinth (*Eichhornia crassipes*), is one of the aquatic species that cover a wide geographic area in the tropical and semi-tropical regions (Kriticos and Brunel, 2016; Degaga, 2018).

The majority of water hyacinth species originated from South America, the Amazon Basin (Parolin et al., 2010; Degaga, 2018) except *E. natans* species, which is native to tropical Africa (Kriticos and Brunel, 2016). Over the years, it has spread widely with a high degree of invasion around the world and is now found in a wide range of water bodies, such as rivers, reservoirs, lakes, ponds, and wetlands (Degaga, 2018; Yan et al., 2017). It has the ecological capacity to quickly cover water bodies, upsetting ecosystems and human activities like fishing and transportation (Robertson et al., 2021; Hassan and Nawchoo, 2020). Currently, the key global hotspots of water hyacinth invasion include the Southeastern United States (Datta et al., 2021), Madagascar (Rakotoarisoa et al., 2015), Tropical Asia (India and Southeast Asia) (Jernelöv, 2017b; Dechassa, 2020), and Lake Victoria in Uganda (Wanda et al., 2015a). In Africa, Water hyacinth was first recorded in Zimbabwe in 1937 and has since spread to various water bodies such as the Zambezi River, Lake Victoria, and the Shire River in Malawi (Villamagna and Murphy, 2010; Kitunda, 2003). Its presence has been documented in multiple countries, leading to widespread infestations over the decades (Williams, 2005; Lu et al., 2007). A recent survey indicated that water hyacinth infestations are rapidly increasing across Africa, particularly in major river systems and lakes, causing severe ecological disruptions and affecting local communities' livelihoods that depend on these water bodies. For example, it has severely affected fishing activities in Kenya, Uganda, and Tanzania, among others (Twongo, 2019; Ageng'o, 2013a). The weed obstructs navigation and fishing routes, leading to reduced fish catches and increased waterborne diseases like malaria and bilharzia due to stagnant water (Atieno, 1999; Yongo et al., 2020; Villamagna and Murphy, 2010).

Its rapid growth, easy adaptability, and resilience to severe environments make them difficult to control once established and impossible to eradicate (Epanchin-Niell et al., 2010; An et al., 2017; Degaga, 2018; Siddiqui et al., 2023). This weed is naturally dispersed by running water, river flow, and flood, or derived by the wind. Unintentionally, humans have also transmitted the plant associated with its use for ornamental purposes (Kriticos and Brunel, 2016). Rapid sexual and asexual reproduction of the water hyacinth has also contributed significantly to its ability to spread throughout the world and create dense infestations (Epanchin-Niell et al., 2010; Siddiqui et al., 2023). In just 6–14 days, the water hyacinth can double its biomass under the right circumstances (Boutahar et al., 2020). Studies in India have shown that in just eight months, 10 plants can replicate into over 655,000, covering half a hectare (Parkhurst et al., 2022). The plant's rapid growth rate and ability to reproduce prolifically in a short period have enabled it to spread to over 50 countries, primarily in the tropics and subtropics (Abba and Sankarannair, 2024).

The expansion of water hyacinth is driven by a combination of eutrophication, water body characteristics, sediment transport, seasonal variability, and geographic factors. Climatic factors such as temperature and rainfall significantly affect the growth of water hyacinth (Rahel and Olden, 2008; Johnston et al., 2017). Warmer temperatures generally promote their proliferation, while rainfall influences nutrient runoff into water bodies, which can enhance growth. Moderate rainfall is optimal for propagation, whereas heavy rain can lead to runoff that may reduce its population size. High nutrient levels lead to increased growth rates and biomass accumulation, allowing the plant to dominate water bodies. Eutrophication, caused by nutrient enrichment (particularly nitrogen and phosphorus) from agricultural runoff and wastewater, creates favorable conditions for water hyacinth (Coetzee and Hill, 2012)

Water hyacinth expansion is significantly influenced by Land use and land cover changes (LULC). Land use and land cover changes, primarily deforestation, agricultural expansion, cropland intensification, and urbanization, have been accelerating globally, driven by human activities and climate change, affecting water hyacinth proliferation (Kutcher and Forrester, 2018; Meneses et al., 2015). Increased nutrient loading, reduced natural vegetation, altered water body dynamics, expansion into bare lands, and urbanization all create favorable conditions for this invasive species. For example, land use changes, particularly converting natural landscapes to agricultural land, often lead to increased nutrient runoff into water bodies (Lee et al., 2017). This eutrophication provides a nutrient-rich environment promoting rapid water hyacinth growth. Studies indicate that areas experiencing agricultural expansion contribute significantly to the nutrient load in adjacent water bodies, facilitating water hyacinth (Vitousek et al., 1997; Damtie and Mengistu, 2022). Tropical regions have experienced significant deforestation, with tree cover loss associated with higher biomass forests, often driven by agricultural expansion for commodity crops.

The invasion of water hyacinth has tremendous opportunities and challenges. It could be used as an input in agricultural activities such as animal feed and compost; for other economic sectors, and has the potential to be used in paper making, furniture, biogas, and ethanol (Harun et al., 2021) and environmental functions is related to nutrient recycling, wastewater management (Malik, 2007; Harley, 1990), and CO<sub>2</sub> sequestration (Djihouessi et al., 2023) among others.

The seriousness of invasive species has been reported by intergovernmental bodies in terms of its effect on species extinction, endangerment, and a major cause of habitat loss. The estimated environmental and socioeconomic damage is up to 5% of the global economy (Day et al., 2018). Though substantial work has been done by states to address the impacts of invasive, less effort has been put in place to facilitate programmatic and systematic action or decisions at international and national levels (Cuthbert et al., 2021).

Globally, the management of water hyacinth has evolved to include a variety of methods, such as mechanical, chemical, and biological controls. While mechanical and chemical methods are commonly used, they often incur high costs and can have adverse environmental effects (Parkhurst et al., 2022; ). Biological control, which involves introducing natural predators, offers a more sustainable solution by aligning with ecological and economic goals (Cuthbert et al., 2021).

Biological control offers a more sustainable and environmentally friendly option for managing invasive species compared to chemical or mechanical methods. Evidence supporting this comes from well-documented case studies, such as the control of water hyacinth in Lake Victoria. There, the introduction of neochetina weevils, natural predators of the water hyacinth, led to a significant reduction in the invasive plant's coverage by about 40% within five years. This biological control effort not only decreased the dense mats that choked waterways but also improved water quality and restored habitats for native species. Another example comes from Florida, where integrated management approaches, combining biological control agents with mechanical removal and careful herbicide use, have successfully managed water hyacinth infestations. This integrated strategy reduced the reliance on chemical herbicides, lowering environmental risks and costs. It also showcased how biological control agents can complement other methods to achieve effective, sustained control of invasive plants (Evans, 2008).

However, sustainable management of water hyacinth requires the involvement of various stakeholders and institutions. Effective stakeholder engagement, which includes local communities, private sectors, NGOs, and government bodies, ensures a comprehensive approach that incorporates diverse insights and

resources (Nega et al., 2024). Integrating policy frameworks with stakeholder participation is essential for aligning management strategies with local and national priorities (Djihouessi et al., 2023).

Despite the growing emphasis on integrated management approaches, challenges remain. These include bureaucratic delays, lack of coordination among institutions, and inconsistent regulatory frameworks, which hinder the swift initiation and implementation of effective management programs (Nega et al., 2024). In Ethiopia, these challenges are compounded by inadequate coordination among stakeholders, further complicating policy implementation (Nega, Ramayya, Afessa, et al., 2022)

The weed's reproductive capacity allows it to rapidly cover wide areas of water bodies once introduced, making it difficult to control and necessitating early intervention before it becomes an entrenched problem. Reliable and timely information on the spatial and temporal distribution as well as dynamics of water hyacinth is important to trace their consequences and potential in susceptible areas.

The proliferation of water hyacinth presents significant ecological and socioeconomic challenges, including biodiversity loss (Villamagna & Murphy, 2010), disruption of navigation and fishing activities (Mironga et al., 2012), and degradation of aquatic ecosystems through oxygen depletion and habitat alteration (Malik, 2007). These impacts are exacerbated by the plant's rapid growth and ability to form dense mats that block sunlight, further destabilizing freshwater ecosystems (Coetzee et al., 2014).

Conversely, water hyacinth offers underutilized opportunities, such as its potential for biofuel production (Rezania et al., 2015) and handicraft manufacturing (Njiru et al., 2020). However, these benefits remain largely unrealized in many affected regions, including Ethiopia, due to inadequate infrastructure, limited market access, and insufficient policy support (Gichuki et al., 2018).

A dual approach—combining control measures with sustainable utilization strategies—is recommended to address this complex issue (Patel, 2012). Effective management requires Mechanical and biological control to limit ecological damage (Hill et al., 2020); the development of local value chains to incentivize harvesting for economic use (Njogu et al., 2019); and Community education and policy frameworks to prevent the unintended spread (van Wilgen et al., 2018).

Shifting from purely eradication-focused efforts to integrated resource recovery could transform water hyacinth from a costly invader into a sustainable commodity, provided that investments in infrastructure, research, and governance are prioritized (Kateregga & Sterner, 2007).

## 1.2 Statement of the Problem

Water hyacinth was first observed in Ethiopia in 1956, specifically along the Koka Lake and Awash River, before spreading to adjacent water bodies (Tolera et al., 2024). From the late 1950s until late 2011, it was not considered a significant weed in water bodies in Ethiopia (Dechassa and Abate, 2020). Over time, however, water hyacinth has proliferated throughout Ethiopia, including in Koka Lake, Lake Tana, Lake Ellen, Lake Abaya, the Baro-Akobo River Basin, and the Awash River Basin, posing substantial challenges to the utilization of these water resources (Tolera et al., 2024; Dechassa and Abate, 2020). The trends and patterns of the proliferation of water hyacinth in Ethiopia, particularly in Lake Tana and the Rift Valley water bodies, brought significant ecological and socio-economic worrisome in the country (Enyew et al., 2020; Dersseh et al., 2020a).

Numerous studies have been conducted on the various dimensions of water hyacinth in, Ethiopia, specifically around Lake Tana. Just a few examples include the socioeconomic effects of water hyacinth on rural communities near Lake Tana (Damtie, et al., 2022a); study on human health and water quality (Gezie et al., 2018); and the efficiency of remote sensing and machine learning in tracking invasive species (Belayhun and Mekuriaw, 2024). According to Enyew et al., (2020), the infestation of the plant has brought negative impact on local economies, transportation, and fishing, calling for immediate action in Lake Tana, Northwestern Ethiopia. Other studies conducted in the lake Tana (Nega et al., 2021; Damtie et al., 2022a) examined the effects of temperature and nutrient level on the infestation level, the potential use and the difficulties of biomass for bioenergy. Damtie et al., (2021), have documented significant increases in water hyacinth coverage in Lake Tana, Ethiopia, highlighting the plant's rapid reproductive capabilities under conducive environmental conditions.

While other studies exist, they lack comprehensive long-term temporal analyses of tracking water hyacinth coverage changes over extended periods and hindering understanding of its growth patterns relative to land use changes and their connection in the Central Rift Valley lake areas of Ethiopia (Zekarias and Gelaw, 2023; Dersseh et al., 2020a). A few studies conducted lack a comprehensive analysis of the feedback loops between land use changes and water hyacinth (Tolera et al., 2024; Desta and Fetene, 2020).

Likewise, water hyacinth has recently proliferated in Ethiopia's Rift Valley waterbodies, raising serious ecological and economic concerns (Dechassa and Abate, 2020). This invasive species has significantly impacted local biodiversity and water management systems by rapidly expanding along water bodies, thereby disrupting aquatic ecosystems and impeding water flow (Yigermal and Assefa, 2019). The spread of water hyacinth disrupts the balance by depleting oxygen, obstructing sunlight, and displacing native

species (Dersseh, Melesse, et al., 2019; Degaga, 2018). These disruptions have led to the decline of biodiversity and the degradation of ecosystem services, affecting the provision of clean water and the health of aquatic life (Degaga, 2018).

The dense mats formed by water hyacinth negatively affect water quality by reducing oxygen levels and blocking sunlight, which in turn harms aquatic ecosystems (Harun et al., 2021). Despite these findings, significant research gaps remain in understanding the full scope of the ecology of water hyacinth in the Rift Valley Lakes of Ethiopia, specifically in lakes Koka and Dembel. This research addresses these gaps by thoroughly assessing the impacts of water hyacinth on water quality, land use, landscape alterations, and fishing activities in the Rift Valley Lakes. This study will provide empirical data to inform policymakers and planners, aiding in the development of targeted management strategies to control the spread of water hyacinth and mitigate its adverse effects ( May et al., 2022; Epanchin-Niell et al., 2010).

Additionally, this study aimed to explore and assess the current state of policies, regulatory challenges, and the roles of institutions and community participation in the management of water hyacinth. By doing so, it seeks to fill the gaps in understanding how these elements can be aligned to facilitate sustainable management practices. By addressing these gaps, the research will contribute to the development of regulatory measures, incentives for biomass utilization, and community engagement strategies. This integrated approach is essential for achieving ecological balance and economic benefits, promoting innovative solutions and adaptive management practices (Djihouessi et al., 2023).

Addressing the water hyacinth problem in Ethiopia is critical for achieving several Sustainable Development Goals (SDGs), particularly those related to clean water and sanitation (SDG 6) and the sustainable use of aquatic ecosystems (SDG 14). From the SDG perspective (Target 17.6), this research is novel in providing information to control and use this invasive weed by global partners through sharing knowledge, expertise, technology, and financial resources in all affected countries. In this respect, the goal of this thesis is to explore the global implications of water hyacinth, the positive and negative effects of water hyacinth on sustainable development. Specifically, this study focuses on understanding the environmental impacts of water hyacinth proliferation in the Rift Valley Lakes of Ethiopia and aims to provide insights into effective management strategies that balance its ecological threats and potential benefits.

### **1.3 Objectives**

The main objective is to examine the long-term spread of water hyacinth in the Koka and Dembel/Ziway Lake catchments in Ethiopia, focusing on its interaction with changes in land use and land cover, assessing its socio-economic and environmental effects, and evaluating the roles of institutions and stakeholders in its management.

#### **Specific Objectives**

- To map and analyze the status and trends of water hyacinth proliferation and implications on land use land cover dynamics in the study area.
- To assess the impacts of water hyacinth on various environmental parameters including water quality, water quantity and availability, land use and cover, landscape alterations, and fishing in the study area.
- To determine the livelihood impacts of water hyacinth, such as crop production, livestock management, and fish harvesting, in the study area.
- To examine communities' willingness to participate in water hyacinth control/ management
- To assess the patterns of institutions and stakeholders' participation in the management of the water hyacinth.

### **1.4 Literature Review**

Water hyacinth (*Eichhornia crassipes*) is a globally recognized invasive species, notorious for its rapid proliferation in aquatic environments. Originating from South America, it escaped cultivation by the early 1900s and has since spread to over 50 countries, primarily in tropical and subtropical regions (Abba and Sankarannair, 2024). Its ability to reproduce both sexually and asexually allows it to double its biomass in just 6–14 days under optimal conditions (Wilson et al., 2000; Degaga, 2018). Water hyacinth disrupts ecosystems, economies, and communities, making water hyacinth a subject of extensive research and management efforts. This review examines the proliferation of water hyacinth, the interplay with land use and land cover dynamics, the ecological and socio-economic impacts of water hyacinth, and the institutions and stakeholders dealing with water hyacinth management.

#### **Historical Context and Global Spread of Water Hyacinth**

Water hyacinth's spread is driven by its rapid reproductive capacity and adaptability to various environmental conditions. Studies from India illustrate its potential for exponential growth, where ten plants can multiply to over 655,000 in eight months, covering significant water areas (Datta et al., 2021). Globally, water hyacinth thrives in nutrient-rich environments, often exacerbated by anthropogenic

activities such as agricultural runoff, which increases nitrogen and phosphorus levels in water bodies (Parkhurst et al., 2022; Abba and Sankarannair, 2024).

In Africa, the plant was first recorded in Zimbabwe in 1937, gradually spreading to major water systems like the Zambezi and Shire Rivers and Lake Victoria (Yongo et al., 2020; Cilliers, 1991; Twongo, 2019). Its presence in these areas has severely impacted fishing activities, obstructed navigation routes, and increased the prevalence of waterborne diseases (Villamagna and Murphy, 2010).

Ethiopia first noted the presence of water hyacinth in 1956 within Koka Lake and the Awash River (Stroud, 1994). The water hyacinth was initially not considered a major threat, but plant's status changed dramatically by late 2011, as it began to spread rapidly across various water bodies, including Lake Tana and the Rift Valley lakes (Ebrahim et al., 2022). The proliferation in Lake Tana has been particularly concerning, with the surface area of infestation increasing by 96% from 2011 to 2019 (Sewunet, Gizeyatu, et al., 2022).

The dynamics of water hyacinth in Ethiopia reflect broader trends observed globally, where eutrophic conditions, climatic shifts, and land use changes provide ideal conditions for its spread. Studies have highlighted how the interplay between these factors and water hyacinth proliferation leads to significant ecological disruptions, affecting biodiversity and water quality (Temesgen et al., 2013; Tolera et al., 2024; Ebrahim et al., 2022).

### **Water Hyacinth Proliferation and Land Use and Land Cover Dynamics**

Water hyacinth proliferation is closely linked to changes in land use and land cover (LULC). Human activities such as deforestation, agricultural expansion, and urbanization contribute to increased nutrient runoff into water bodies, creating favorable conditions for water hyacinth growth (Yohannes et al., 2017). The conversion of natural landscapes to agricultural land often results in eutrophication, promoting the rapid spread of invasive species (Zekarias and Gelaw, 2023).

In Ethiopia's Rift Valley, the expansion of water hyacinth is influenced by these LULC dynamics. Studies have shown that land use changes, particularly in the conversion of forested areas to agricultural land, exacerbate nutrient loading in water bodies, facilitating water hyacinth proliferation (Desta and Fetene, 2020; Bekele et al., 2018). This interplay underscores the need for integrated management approaches that consider both land and water resource management.

This interplay highlights the critical need for integrated, watershed-scale management strategies that address the inextricable linkages between terrestrial and aquatic systems. Land-use practices (e.g., agriculture, deforestation, urbanization) directly alter hydrological regimes, sediment loads, and nutrient

fluxes into water bodies, exacerbating challenges like eutrophication, habitat degradation, and water scarcity (Vörösmarty et al., 2010). Conversely, water resource management decisions (e.g., dam operations, irrigation withdrawals) can reshape land productivity and ecosystem resilience (Grafton et al., 2019).

For instance, uncontrolled agricultural runoff may increase phosphorus inputs to lakes (Carpenter et al., 1998), while inefficient irrigation policies can deplete groundwater, compounding soil salinization (Famiglietti, 2014). A siloed approach, managing land and water separately, fails to mitigate these feedback loops. Instead, holistic frameworks (e.g., Integrated Water Resources Management [IWRM]; Global Water Partnership [GWP], 2000) are essential to: coordinate policies across sectors (agriculture, energy, conservation); balance trade-offs (e.g., food security vs. ecological flows), and enforce adaptive governance that responds to dynamic socio-environmental conditions.

Case studies, such as the Rhine Basin's transboundary cooperation (Huisman et al., 2000) and Kenya's Water Towers Initiative (Oguge et al., 2021), demonstrate how integrated systems reduce conflicts and enhance sustainability. Thus, harmonizing land-water interactions is not merely beneficial but a prerequisite for long-term resource security in an era of climate uncertainty (IPCC, 2022).

### **Strategies for Managing Water Hyacinth**

Various strategies have been explored to manage water hyacinth, each with its advantages and limitations. Mechanical removal, chemical herbicides, and biological controls are among the conventional methods employed. Mechanical removal involves physically extracting the plant from water bodies, which can be effective but is labor-intensive and costly. Chemical herbicides offer a more immediate solution but are often criticized for their potential environmental harm and long-term sustainability (Djihouessi et al., 2023).

Biological control, which involves introducing natural predators like specific insects, is viewed as a sustainable alternative. This method offers a balanced approach that aligns with ecological and economic goals (Harley, 1990; Karouach et al., 2022). In Ethiopia, research has assessed the use of bioagents, such as weevils, highlighting their potential in controlling water hyacinth populations (De Groote et al., 2003). However, the effectiveness of these methods can vary across different ecological settings, necessitating multi-year field studies to evaluate integrated management strategies under Ethiopian conditions (Jafari, 2010; Harun et al., 2021).

Innovative management strategies are also being explored. These include using water hyacinth biomass for bioenergy production or as raw material for paper and textile industries. Such an approach not only

helps in controlling the weed but also creates economic opportunities for local communities. However, these strategies require significant investment in research and infrastructure to be viable on a large scale.

### **Stakeholder Involvement**

Effective management of water hyacinth requires the active involvement of diverse stakeholders, including local communities, government agencies, NGOs, and private sector entities. Stakeholder engagement is crucial for ensuring that management strategies are well-informed, culturally appropriate, and sustainable (Zikargae, 2022). Participation can take various forms, such as direct involvement in removal activities, financial support, policy advocacy, and educational outreach programs (Zikarga, 2018).

Studies have shown that when local communities are engaged, control measures are more effective and have longer-lasting impacts (Nega et al., 2021). Community-based management approaches empower local stakeholders to take ownership of the problem and implement solutions tailored to their specific context. However, barriers such as lack of awareness, insufficient resources, and inadequate institutional support can hinder effective collaboration (Ebro et al., 2017; Seboka et al., n.d.).

Successful stakeholder engagement requires clear communication, capacity building, and the establishment of trust among all parties involved. Collaborative efforts should focus on shared goals and mutual benefits, ensuring that the interests of all stakeholders are considered and addressed.

### **Policy Frameworks and Institutional Roles**

Policy frameworks play a pivotal role in the sustainable management of water hyacinth. These frameworks should integrate policy instruments, including informational, economic, and regulatory measures, to promote sustainable biomass utilization (Nega et al., 2021). Global and regional policies often designate water hyacinth as a noxious weed, necessitating coordinated management efforts across borders (Abba and Sankarannair, 2024).

In Ethiopia, studies emphasize the need for comprehensive policy frameworks that manage water hyacinth effectively. However, policy implementation faces challenges such as overlapping responsibilities and inadequate coordination among stakeholders (Getnet et al., 2014). Institutions, such as water bodies protection and development agencies, are crucial in coordinating efforts and providing governance and technical support (Sewunet et al., 2022).

Effective policy frameworks should be adaptive, allowing for flexibility in response to changing ecological and socio-economic conditions. They should also encourage innovation and collaboration

among various sectors, facilitating the development and implementation of integrated management strategies.

Water hyacinth remains a formidable ecological and socio-economic challenge, requiring concerted efforts from multiple stakeholders. Successful management necessitates integrated strategies that balance ecological, economic, and social considerations. Continued research and adaptive management will be essential to mitigate the impacts of this invasive species and ensure sustainable ecosystem and community resilience. By leveraging the strengths of diverse stakeholders and aligning policy frameworks with local needs, it is possible to address the challenges posed by water hyacinth effectively.

## **1.5 Conceptual Framework**

The proliferation of water hyacinth is rooted in a dynamic interplay of drivers such as population growth, economic activities, ecological changes, and policy gaps. As the population grows, there is an increased demand for resources, which intensifies agricultural practices and accelerates urban expansion. Economic activities, while contributing to development, often overlook long-term environmental sustainability, thus heightening pressures on natural ecosystems. Ecological changes, whether driven by human activity or natural events, can create favorable conditions for the spread of invasive species like water hyacinth. These drivers are further compounded by policy gaps, where insufficient or poorly enforced regulations allow these pressures to escalate unchecked.

These drivers exert significant pressure on the environment, manifesting in actions like deforestation, intensive agriculture, urbanization, and overgrazing. Deforestation, often undertaken to facilitate agriculture or urban development, reduces natural habitats and increases nutrient runoff into water bodies. Intensive agricultural practices, characterized by the use of high levels of fertilizers and pesticides, further contribute to nutrient pollution, setting the stage for water hyacinth proliferation. Urbanization not only increases impervious surfaces but also disrupts natural hydrological cycles, resulting in increased water pollution events. Overgrazing degrades the land, contributing to soil erosion and nutrient runoff, thereby magnifying the environmental pressure.

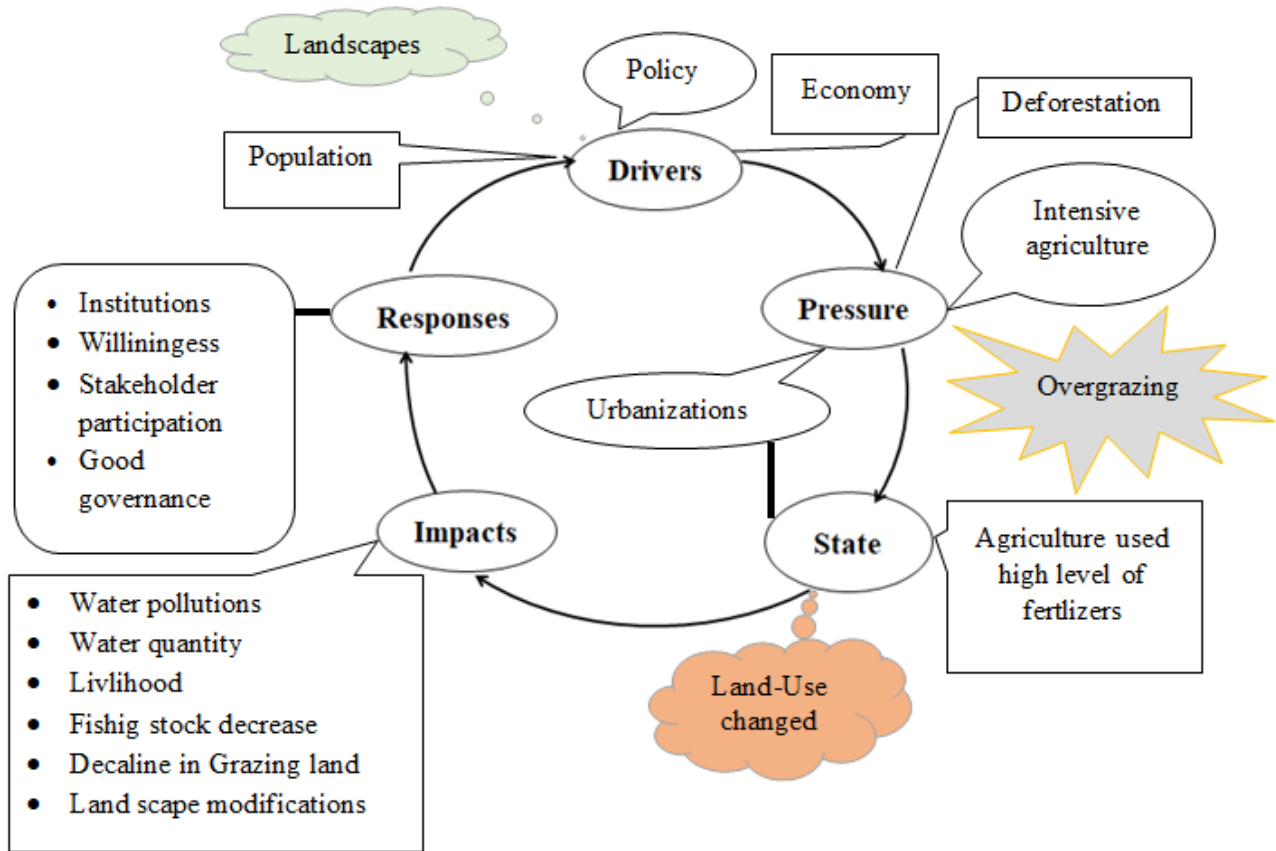
These pressures alter the state of the environment, leading to significant land-use changes, urban expansion, and high fertilizer use in agriculture. Such changes disrupt ecosystem dynamics and nutrient flows, resulting in ecological imbalances. As natural landscapes are converted to agricultural or urban areas, the disruption of nutrient cycling and hydrology makes aquatic systems more vulnerable to invasive species. Urban expansion not only increases runoff but also contributes to the pollutant load entering water systems. The high use of fertilizers in agriculture elevates nutrient levels in water bodies, creating conditions that favor the proliferation of water hyacinth.

The impacts of these changes are far-reaching, affecting water quality, quantity, livelihoods, fishing activities, grazing lands, and landscape aesthetics. Elevated nutrient loads lead to eutrophication, degrading water quality and depleting oxygen levels, which can harm aquatic life. The excessive growth of water hyacinth impedes water flow and access, affecting water availability. Communities that rely on fishing and agriculture face economic challenges, as the invasive species disrupt fishing activities and reduce the availability of arable and grazing lands. Additionally, the presence of water hyacinth alters the natural landscape, affecting ecosystem functions and aesthetic values.

Responses to these challenges must involve a coordinated effort among institutions, communities, stakeholders, and governance structures. Effective management of water hyacinth requires robust institutions to coordinate cross-sectoral strategies and implement sustainable practices. Engaging communities and encouraging their participation in management efforts are crucial for fostering ownership and responsibility. Collaborative efforts with diverse stakeholders, including local governments, NGOs, and the private sector, can enhance the effectiveness of management strategies. Good governance, characterized by transparency, accountability, and inclusivity, is essential for ensuring that policies and interventions are implemented effectively and equitably. These responses aim to address the drivers, pressures, states, and impacts of water hyacinth proliferation, ultimately restoring ecosystem balance and promoting sustainable development.

The interaction among these elements is cyclical. Drivers lead to pressures, which change the state of the environment, resulting in impacts that necessitate responses. Effective responses can mitigate drivers and pressures, stabilizing the state and reducing impacts, thereby creating a feedback loop that can either exacerbate or alleviate the water hyacinth problem, depending on how well the responses are implemented and adapted over time (Figure 1).

- **Drivers:** Populations, Economic, Landscapes, Policy
- **Pressure:** Deforestation, Intensive Agriculture, Urbanization, Overgrazing
- **State:** Land use change, Urban expansion, Agriculture used a high level of fertilizers
- **Impacts:** Water pollution, Water quantity, Livelihood, Fishing stock decline, Grazing land Degradation, Landscape modifications
- **Responses:** Institutions, Willingness to, Stakeholder participation, Good governance



**Figure 1.** DPSIR Conceptual Framework of the study (adapted from Tscherning et al., 2012)

## 1.6 The Study Area

The study area (Fig. 2) is located in the Rift Valley Lakes of Ethiopia and encompasses two lakes: Koka and Dembel, the largest freshwater lakes in the central part of the country. Lake Koka is located between 8°28' to 59.99' N latitude and 39°9' to 60.00' E longitude, at 1590 m a.s.l. elevation. The lake's total area is approximately 255 km<sup>2</sup>, with a length of 20 km and a width of 15 km. The lake has a shoreline length of 19.5–20.5 km and has a maximum and minimum depth of 14 m and 9 m, respectively. The Mojo and Awash rivers are the two major rivers draining into the lake. Although Koka Lake was originally developed for hydropower generation, the lake is currently used for fish production, irrigation, and flood control from downstream areas. The predominant land use/cover in the Koka catchment are agriculture (both irrigated and rainfed) and rural settlements.

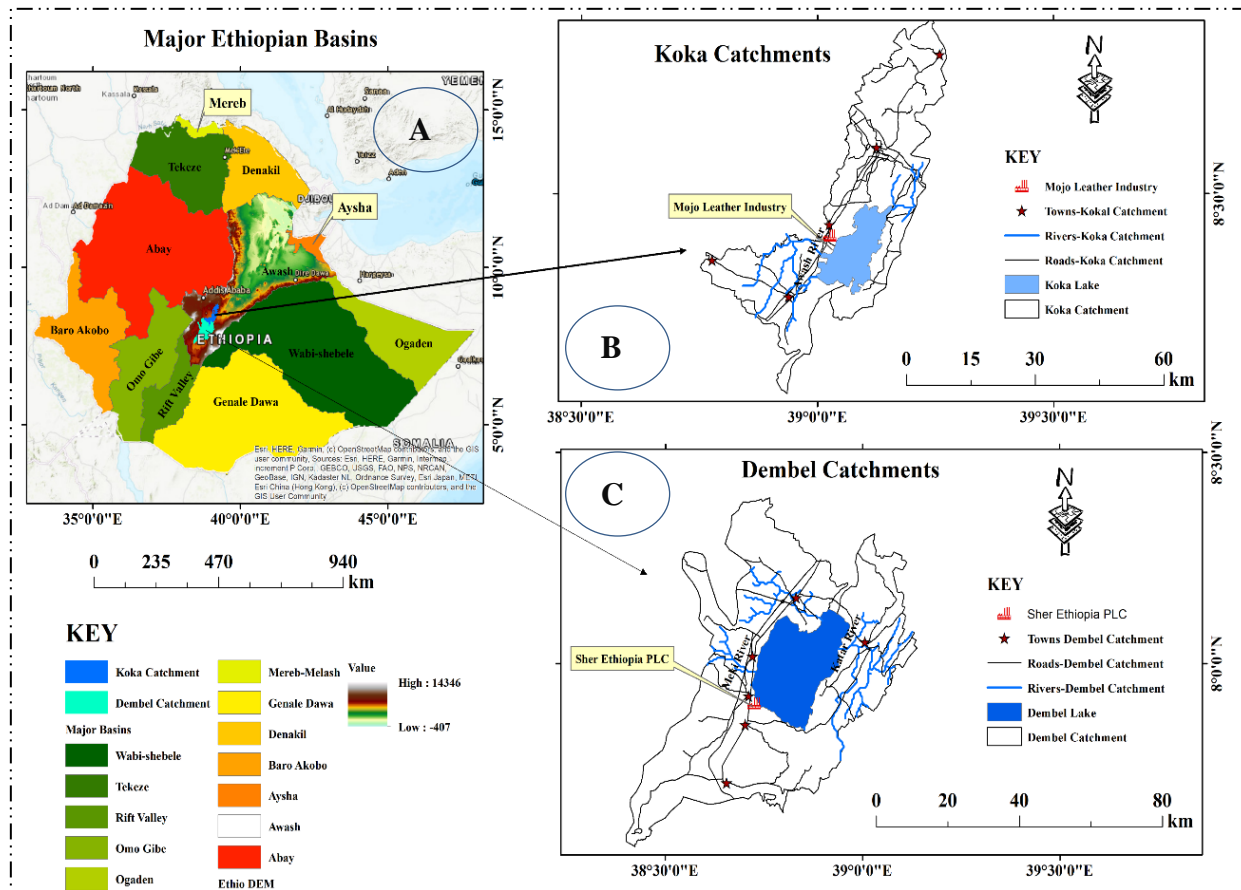
The study focused on both the lakes and the surrounding landscapes. The study focused primarily on the lake bodies (Koka and Dembel) to assess the direct impacts of water hyacinth on water quality, aquatic ecosystems, and fishing activities. While the surrounding landscapes influence nutrient runoff and the consequent impacts on hyacinth progression, their inclusion would require broader hydrological and land-

use modeling. To this effect, we have undertaken an investigation to assess the dynamics of the land use and land cover of the surrounding landscape and their impacts on water hyacinth.

Water hyacinth is the dominant macrophyte in Lake Koka, followed by *Leptochloa caerulescens* Steud., *Echinochloa stagnina* (Retz.) P. Beauv., and *Typha angustifolia* L. The existence of this invasive plant, Water Hyacinth, on the lake was first reported in 1956, and since then, the weed has been causing immense ecological and socio-economic damage in the area. The plant is known for its rapid and extensive vegetative reproduction and high seed production.

Lake Dembel lies between 8°00'00" N latitude and 38°50'00" E longitude, at 1636 m.a.s.l., and has an estimated surface area of 485 km<sup>2</sup>, with a width of 20 km and a length of 31 km. The lake has a maximum depth of 8.95 m and a mean depth of 2.5 m and is considered the shallowest lake in the Rift Valley. The lake's surface area fluctuates between 435 and 485 km<sup>2</sup> depending on the water inflow. The two major rivers that flow into Lake Dembel are the Ketar and Meki Rivers. Lake Dembel is a freshwater lake that supports different uses, including water supply, irrigation, fishing, and recreation. The lake is being degraded primarily because of various water and land-use activities in its catchment. There is an ongoing agricultural transformation. Both small-scale farmers and large horticultural companies use huge amounts of pesticides and fertilizers that have led to nutrient loading, a conducive environment for the proliferation of macrophytes like water hyacinth, which is currently invading the lake at an alarming rate. The expansion of water hyacinth has been threatening the existence of the water body and the surrounding biodiversity.

Water flows through the riverbanks, and runoff contributes to water hyacinth seed transport into the lakes (Churko, Nhamo, et al., 2023). Similar studies indicated that the feet of animals and beaks of birds contribute to the spread of water hyacinth because they feed in sites of water hyacinth infestation and carry the seed over considerable distances by their bodies. Common aquatic macrophytes around and in Lake Dembel include *Cyperus alopecuroides* Rottb. (aquatic sedge), *Phragmites karka* (Retz.) Trin., and *Paspalidium geminatum* (Forssk.).



**Figure 2.** A) Location of Ethiopia in East Africa, B) Koka catchment boundary and other natural and man-made, C) Dembel catchment boundary and other natural and man-made.

(Source: Own-produced map 2024 using Spatial Data Sources)

## 1.7 General Methodology

The process of collecting and analyzing satellite imagery, particularly for studies related to land use land cover changes and water hyacinth expansion, involves several systematic steps.

Landsat satellite images (specifically Landsat 5 and 8) from 1996, 2004, 2014, and 2024 were used to analyze water hyacinth changes (Table 1). Additionally, land cover changes such as deforestation, agricultural land expansion, urban land change, grassland change, and wetland alteration were also analyzed (Jensen, 2009).

Water quality data were acquired from water lab analysis, while the qualitative data and quantitative data were gathered from surveys and key informant interviews.

**Table 1.** Summary of the data collection and analysis is given in the table

<b>Theme (Chapters)</b>	<b>Data Type and sources</b>	<b>Data collection methods tools, and models</b>	<b>Data analysis</b>
Meta Review	-Published articles on social, environmental, and economic impacts of Water Hyacinth  -Electronic databases- Science Direct, Pub-Med, Google Scholar, and Google were used.	-Preferred Reporting Items of Systematic Reviews and Meta-Analysis (PRISMA)  -Application ATLAS.ti software	-Query, networks, and quotations- qualitative data analysis -Code co-occurrence table – quantitative data analysis.
Land use land cover classification	-Remote Sensing Data Source (Satellite data series)  -Secondary data sources including published and unpublished documents	-FGD & KII  -GEE platform (Script-based) using RFC (Satellite Image Processing: (Pre and Post))  -HH Questionnaire -Humanitarian Data Exchange (PD, DEM)  -Landsat Series: (5ET, Landsat 7ETM+ and 8 OLI)	-LULCC*-Automated Intersection Method (using Geo-processing tool in AGIS Environment).  -Descriptive statistics  -Satellite Image Processing: (Pre and Post)
Environmental Impacts	-Water quality data -Published and unpublished documents	-Water quality analysis	-Quantitative data analysis -Descriptive statistics
Livelihood impacts	-Socio-Economic-Cross-sectional HH survey DATA -Published and unpublished documents	-FGD & KII  -Secondary data sources  -HH Questionnaire using Cobo toolbox	PMS DID  WLS
Willingness to participate	Socio-Economic Cross-sectional HH DATA	-HH Questionnaire  -FGD and KKI  -Secondary data sources  -SPSS, STATA	-Seemingly unrelated bivariate probit model  -Descriptive statistics
Institutions and stakeholders	-Policy and strategy documents  -Published and unpublished documents	-Review of policy and strategy documents and related published and unpublished documents	-Qualitative analysis

## 1.8 Ethical Consideration

The ethical procedures followed in this research include obtaining informed consent from all participants involved in interviews, surveys, and focus group discussions, ensuring the confidentiality of personal data, and integrating the perspectives of local stakeholders into the study. The research adhered to ethical

guidelines by prioritizing the well-being of the local communities and ecosystems, ensuring that management strategies are sustainable, and transparently communicating the study's findings to the relevant stakeholders and policymakers.

## **1.9 Dissertation Organization**

This dissertation is organized into seven chapters, each addressing different aspects of the water hyacinth invasion in Ethiopia's Rift Valley lakes. Chapter One introduces the research problem, providing a background on the spread of water hyacinth, its environmental and socio-economic impacts, and its significance. It outlines the study's objectives, research objectives, study area and methodology, establishing a foundation for understanding the broader effects of this invasive species on ecosystems, local communities, and national policies.

Chapter Two presents a systematic review and meta-analysis of global literature on the environmental and socio-economic impacts of water hyacinth. By synthesizing data from case studies, this chapter links these impacts to key Sustainable Development Goals (SDGs) and critically examines the worsening issues related to ecosystem services, public health, and poverty. It provides a global perspective, offering a benchmark for comparing the situation in the Rift Valley.

Chapter Three focuses on the Rift Valley, analyzing the spread of water hyacinth in Koka and Dembel Lakes. Using satellite data, historical records, and field observations, it tracks the species' growth and identifies the factors influencing its spread. It also explores the relationship between land use/land cover changes and the spread of water hyacinth. It investigates the role of agricultural expansion, urbanization, and deforestation in the proliferation of the species.

Chapter four examines the environmental impacts of water hyacinth on Koka and Dembel Lakes. Through fieldwork, including water quality assessments and biodiversity monitoring, the chapter documents change such as oxygen depletion, biodiversity loss, and disruptions to water transport. By comparing pre- and post-invasion data, it offers insights into the health of the lake ecosystems and future management needs.

Chapter five explores the socio-economic effects of the invasion on local communities, particularly those dependent on fishing, agriculture, and water resources. Through surveys and interviews, it examines the changes in income, livelihoods, and community resilience, shedding light on the coping mechanisms employed by local populations.

Chapter six investigates community willingness to engage in water hyacinth management, focusing on household labor. It assesses factors influencing local participation in control efforts, such as perceived benefits, social norms, and available resources, offering a perspective on improving community involvement for more effective management.

Chapter seven reviews institutional frameworks and governance related to the issue, evaluating existing policies and community participation in decision-making. It suggests improvements to enhance coordination and local involvement in managing water hyacinth.

The final chapter synthesizes the research findings, offers practical recommendations for policymakers, local communities, and environmental managers, and proposes directions for future research to address unresolved challenges in water hyacinth management.

## **Chapter 2: Environmental and Socio-Economic Impact of Water Hyacinth: Systematic Review and Meta-Analysis**

### **Abstract**

*Water hyacinth is one of the alien invasive plants aggressively spread worldwide across the tropics. It is a global issue linked to the Sustainable Development Goals that needs collective action to reduce the impact on natural habitat degradation, biodiversity loss, social conflict, and economic loss. It has caused adverse effects on the ecosystem services, economic activities, and social affairs. Though several individual efforts have been made to divert the challenges of water hyacinth, it did not bring a sustainable solution. These threats can be averted by maximizing its use associated with socio-economic and environmental opportunities. So, systematically induced information on the dynamics of water hyacinth is important to trace their consequences. Thus, this paper fills the information gap to tackle the threat and maximize the opportunities in the global context. The result of a systematic review shows the adverse effects of water hyacinth outweigh its benefits globally. Moreover, its impact is high overall in African countries and specifically in Ethiopia. Its effect on ecosystem services is high in other African countries as compared to the global and Ethiopian context. The benefits of water hyacinth are narrated in the economic sector as well as in provisioning and regulating services. So, mobilizing global resources such as knowledge, technology, finance, and innovation are significant to control and utilize the opportunities related to water hyacinth invasion. While strategic resource use optimization can mitigate localized threats, its systemic scaling without safeguards may exacerbate global pressures (e.g., biodiversity loss, carbon footprints). In the national context, integrating invasive weed management strategy into the policies and adopting the best lessons significantly contributes to managing water hyacinth.*

**Keywords:** ATLAST.ti, Biodiversity, Control, Effect, Invasive Species, Threat

## 2.1 Introduction

Invasive species are inhabitants of water bodies as well as terrestrial which are not native to that area (Simberloff, 2015). These species include plants, animals, and microbes that primarily invade the area through human intrusion (May, 2007). Though it provides several services for aquatic life, it causes a huge threat to the survival of native living organisms and ecosystem services. The risk associated with invasive species attracts global attention, allied to the impact on ecosystem goods and services, which would, in turn, impose an influence on human wellbeing and biodiversity loss (May, 2007; United Nations, 2018). Water hyacinth is one of the aquatic and wetland species that cover a wide geographic area in the tropical and semi-tropical regions (European and Mediterranean Plant Protection Organization, 2008; Pan et al., 2012).

Water hyacinth is propagated by sexual and asexual methods. Sexually, it bears a large number of seeds which can live for many years in the natural seed bank (European and Mediterranean Plant Protection Organization, 2008). Asexually, it is multiplied by budding and stolon production (Sharma and Aggarwal, 2020). This weed is naturally dispersed by running water, river flow, and flood, or derived by the wind. Unintentionally, humans have transmitted the plant associated with its use for ornamental purposes (European and Mediterranean Plant Protection Organization, 2008). Moreover, its floating, fast-growing, and adaptive phenological behavior, among other characteristics, makes it invade wider areas within a short period (Pan et al., 2012; Zhang and Guo, 2017).

Most water hyacinth species originate in South America, the Amazon Basin (Navarro and George, 2000; Pan et al., 2012) except *E. natans* species, which is native to tropical Africa (European and Mediterranean Plant Protection Organization, 2008). It spreads out with a high degree of invasion around the world and is now found in a wide range of water bodies such as rivers, reservoirs, lakes, ponds, and wetlands within the range of temperatures between 12°C to 36°C (Pan et al., 2012; Zhang and Guo, 2017).

Water hyacinth (*Eichhornia crassipes*) is infamous for its extraordinary reproductive capacity, which fuels its rapid spread and invasive success (Villamagna & Murphy, 2010). It reproduces both sexually, through seed production, and asexually, via vegetative propagation. A single plant can generate up to 5,000 seeds annually, and these seeds remain viable in the sediment for 15–20 years, enabling population recovery even after eradication efforts. Vegetative reproduction occurs through stolons—horizontal runners that produce genetically identical daughter plants. Under optimal conditions (e.g., warm temperatures and nutrient-rich waters), water hyacinth can double its biomass in 6 to 18 days (Gopal and Sharma, 1990; Mailu, 2001; Zheng et al., 2010).

This dual reproductive strategy allows *E. crassipes* to rapidly colonize water bodies, forming dense mats that block sunlight, reduce dissolved oxygen, and displace native biodiversity. Its resilience complicates management, often necessitating integrated approaches (mechanical, biological, and chemical controls) to suppress populations effectively (Villamagna & Murphy, 2010; Zheng et al., 2010).

Water hyacinth could have opportunities and challenges for the socio-economic activities and environmental functions. It could be used as an input in agricultural activities such as animal feed and compost; for other economic sectors, it is used to produce paper, furniture, biogas, and ethanol (Sharma and Aggarwal, 2020); Its environmental functions are related to nutrient recycling, wastewater treatment (European and Mediterranean Plant Protection Organization, 2008), and CO<sub>2</sub> sequestration (Sharma and Aggarwal, 2020) among others.

The adverse effect of water hyacinth is reflected in environmental, economic, and social aspects. The environmental impact is assessed in terms of ecosystem goods and services. Similarly, the economic impact is reviewed on crop production, fish catches, livestock production, input supply, and cost of maintenance and management. Likewise, the social impact is seen from the perspective of its effect on human health, labor performance, and social conflicts. This shows how this invasive weed is within the SDG agenda target 15.8 which emphasizes minimizing the impact of aggressive species.

The narrated environmental, economic, and social impact of water hyacinth is high in Africa as compared to other regions due to some reasons. First, almost all African countries are located in the Tropical region, which is conducive for the expansion of the weed. Second, little is known about the alternative use and control mechanisms of the exotic invasive weed results in exacerbating its effect. Third, most of these developing countries couldn't afford to access new technologies to overcome and minimize the overgrowing adverse effects. Since these countries are directly benefiting from the environmental goods and services, their impact on the environment has been studied in different parts of the continent as compared to other regions.

The seriousness of invasive species has been reported by intergovernmental bodies in terms of its effect on species extinction, endangerment, and a major cause of habitat loss. The estimated environmental and socioeconomic damage is up to 5% of the global economy. Though substantial work has been done by states to address the impacts of invasive, less effort has been put in place to facilitate programmatic and systematic action or decisions at international and national levels (Young et al., 2017).

Reliable and timely information on the spatial and temporal distribution as well as dynamics of water hyacinth is important to trace their consequences and potential in susceptible areas. Concerning the global

challenge of the weed, information is hardly integrated to tackle the threat and maximize the opportunities. Moreover, integrated measures to prevent and reduce the impact of invasive species in terms of achieving SDG (Target 15.8) are scarce. From the SDG perspective (Target 17.6), this paper is novel in providing information to control and use this invasive weed by global partners through sharing knowledge, expertise, technology, and financial resources in all affected countries. In this respect, the goal of this paper is to review and fill the gaps in global implications, the positive and negative effects of water hyacinth, on sustainable development. Specifically, it deals with the diversified impact of water hyacinth on the environment, economy, and society.

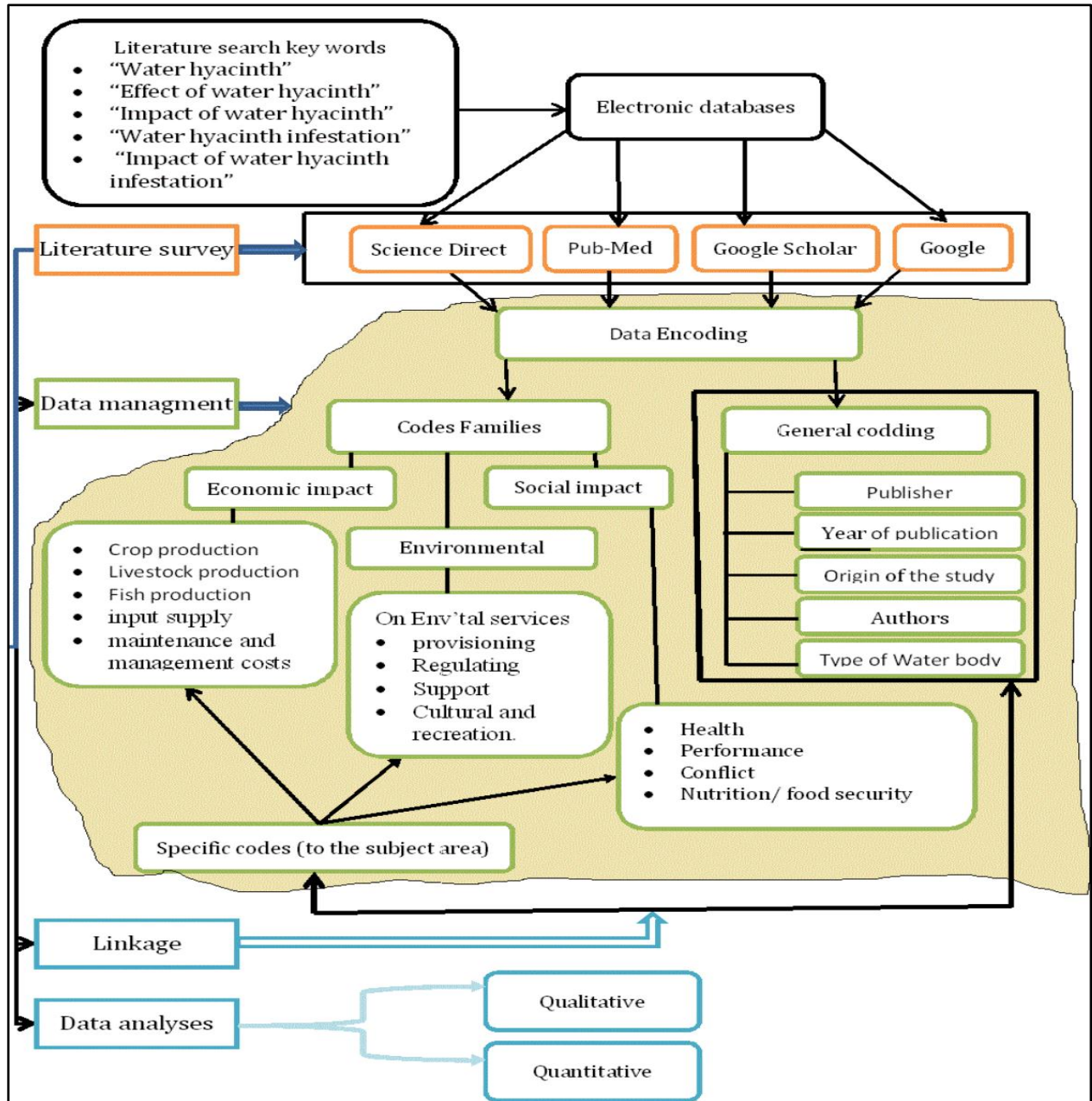
## **2.2 Method of Data Collection and Analysis**

Figure 3 depicts the methodological framework of the systematic review and meta-analyses. Preferred Reporting Items of Systematic Reviews and Meta-Analysis (PRISMA) are followed to address the impact of water hyacinth at the Global, African, and Ethiopian contexts. The Figure summarizes all the activities starting from literature management to data analysis. Electronic databases such as Science Direct, Pub-Med, Google Scholar, and Google were used. Literature management was done by searching and identifying relevant papers, setting codes, extracting quotations, and grouping primary documents based on code and memo into the same family.

First, literature was searched by identifying and using keywords as a search tool. These are “Water hyacinth”, “Effect of water hyacinth”, “Impact of water hyacinth”, “Water hyacinth infestation”, and “Impact of water hyacinth infestation”. Second, data was managed in the ATLAS ti Software. Coding was done after identifying and removing articles that were duplicated and out of the scope of the study. General codes were secure based on different criteria. It starts with a general coding system like publisher, number of authors, publication year, origin of the study, and the type of water body. Specific codes were made regarding the economic, environmental, and social impact of water hyacinth. The economic impact is further classified into families. The families are created based on their impact on crop production, fish production, livestock production, input supply, and maintenance and management costs. Similarly, the environmental impact further classified its role on ecosystem services such as provisioning, regulating, support services and cultural and recreation. Likewise, the social impact is categorized into its effect on health, labor performance, and conflict.

Third, based on the information in the papers, data was extracted by relating the codes with the quotes. Memos were also used when relevant to explain and categorize the quotations, which were used to classify related codes in a memo family. Last, the meta-analyses were done by qualitative and

quantitative methods. Query, networks, and quotations were used to analyze qualitative data whereas quantitative data analyses were done by code co-occurrence table which is used to compute frequency.



**Figure 3.** Methodological framework, a PRISMA approach

### Data Acquisition and Description

The impact of water hyacinth in the Global, Regional, and Ethiopian context is assessed by browsing articles from Science Direct, PubMed, Google Scholar, and Google Search from January 5, 2024, to April 23, 2024, written by three authors. A combination of keywords such as “Water hyacinth”, “Effect of

water hyacinth”, “Impact of water hyacinth”, “Water hyacinth infestation”, and “Impact of water hyacinth infestation” was used to search the articles. Accordingly, a total of 63 articles were collected from Science Direct (24), Pub-med (5), Google Scholar (9), and Google (25). A total of 29 articles were rejected due to duplication and unrelatedness to the objectives. Data from 34 articles were managed using ATLAS ti software.

General data was collected and coded from the potential articles. As shown in Table 1 the articles are generally categorized into published before and after 2015 considering the Sustainable Development Goals (SDG). About 74 percent of the articles were published in 2015 and onward while 26 percent were released before this year. This information highlights the economic, environmental, and social impact of water hyacinth in general and specifically its position to the SDGs (Desa, 2018). Similarly, most of the articles are prepared by three (32%) and single (24%) authors. The remaining five articles were prepared by five authors, two triplets of articles prepared by six and four authors, and the last two pairs of articles prepared by two or more than six authors. Concerning the origin of the articles, 38 percent of the articles are done in African countries excluding Ethiopia, 35 percent in Ethiopia, and the rest 27 percent are done in the global context. This information would give a general clue about the spatial concern of water hyacinth invasion. Generally, the articles reported that this invasive weed would pose 87 percent negative and 13 percent positive impacts on economic, environmental, and social circumstances (Table 2).

**Table 2.** Description of coded general data collected from the articles

<b>Name</b>	<b>Frequency /Quotes</b>	<b>Percent</b>
Year of Publication (n= 34)		
Published onward 2015	25	74
Published before 2015	9	26
Number of authors (n= 34)		
3	11	32.4
1	8	23.5
5	5	14.7
4	3	8.8
6	3	8.8
2	2	5.9
> 6	2	5.9
Case of the article (n= 34)		
African countries (other than Ethiopia)	13	38.2
Ethiopia	12	
Global (other than African countries)	9	26.5
Impact of water hyacinth (number of Quotes = 88)		
Negative	78	88.6
Positive	10	11.4

## 2.3 Results and Discussion

### 2.3.1 Impact of Water Hyacinth - Spatial Perspective

Water hyacinth mostly affects countries located in the tropical region. Recalling its origin and expansion path, water hyacinth covers large geographic areas. The impacts of water hyacinth in Ethiopia, Africa, and globally are categorized in the form of environmental, economic, and social settings. Table 3 shows that 43 percent of the impact was quoted in Ethiopia, 30 percent in Africa, and 28 percent globally. Likewise, 51 percent of the impact is on the environmental/ecosystem services, 32.7 percent on economic activities, and 16.3 percent on social aspects. The ecosystem service affected by water hyacinth is reported in Africa (38%) is more than the global (34%) and Ethiopia (28%). The highest impact of water hyacinth on the ecosystem services reported in Africa is on provisioning service (41%), support service (57%), and cultural and recreational services (50%), whereas the impact on regulating service is high in the global context (64).

The economic impact is high in Ethiopia, such as on fish production (55%), crop production (75%), weed management and maintenance cost (63%), and livestock production (80%). Yet globally, the economic impact on input supply is high. Similarly, the social impact of water hyacinth is high in Ethiopia, particularly on health and labor performance, while its impact on social conflict is reported only in the global context. These results lead to explain the detail information on the positive and negative impacts. Hence, the next section briefs how and why the extent of its adverse effect is linked more specifically to the origin of the article (Table 3).

**Table 3.** The impact of water hyacinth reported by the articles

Impact of water hyacinth (Quotes=104)	Case of the article (in Percent)		
	Ethiopia (42.3%)	Africa (29.8%)	Global (27.9%)
Environmental impact/effects (n= 53)	28.3	37.7	34.0
Provision service (n=29)	24.1	41.4	34.5
Regulating service (n=11)	27.3	9.1	63.6
Support services (n=7)	42.9	57.1	0.0
Recreational and cultural services (n=6)	33.3	50.0	16.7
Economic impact/effect on (n=34)	61.8	20.6	17.6
Fish production (n=11)	54.5	27.3	18.2
Crop production (n=8)	75.0	12.5	12.5
Management and maintenance cost (n=8)	62.5	25.0	12.5
Livestock production (n=5)	80.0	20.0	0.0
Input supply (n=2)	0.0	0.0	100.0
Social impact/effects on (n=17)	47.1	23.5	29.4
Health (n=9)	55.6	22.2	22.2
Labor performance (n=7)	42.9	28.6	28.6
Conflict (n=1)	0.0	0.0	100.0

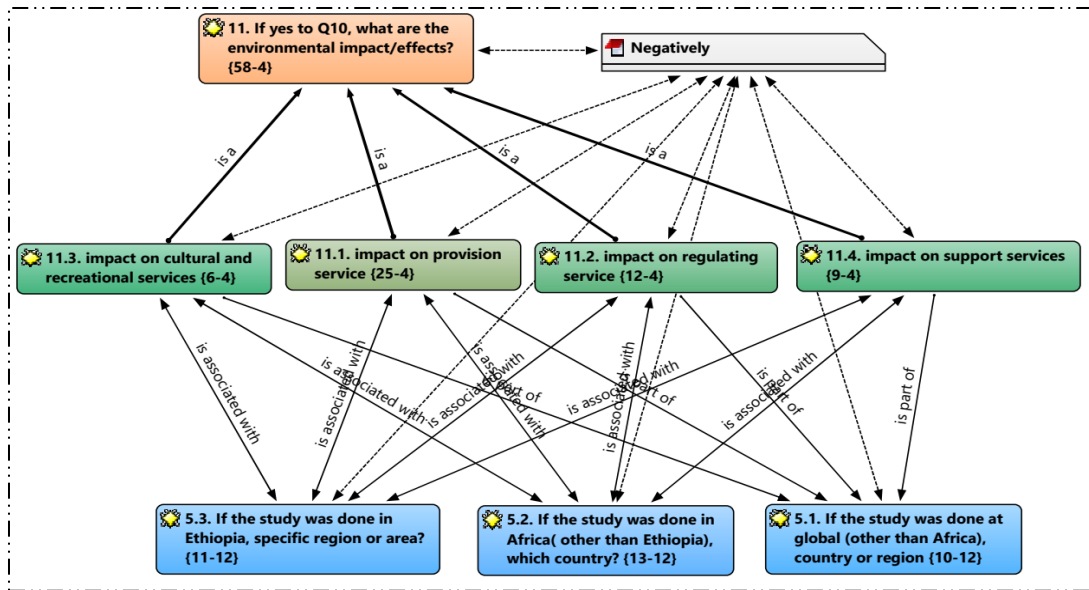
### **2.3.2 Benefits of Water Hyacinth**

The progressive effect of water hyacinth is assessed on its positive impact on input supply, provisioning, and regulating services narrated in several contexts. Globally, water hyacinth is used as an input for different household products in Indonesia (Maulidyna et al., 2021). Its roles in sequestering GHGs (Oliveira et al., 2021) and aquaculture sanctuary (Basaula et al., 2023; Hill et al., 2021) are also payback effects. In Africa, its environmental benefit is narrated as a facilitating effect on the nutrient cycle in Zimbabwe (Rommens et al., 2003a) and absorbing heavy metal in Ethiopia (Endgaw, 2020).

The practice of using water hyacinth as an input for manufacturing household products in Indonesia should be a lesson in other affected areas as an additional income source to eradicate extreme poverty (SDG1, Target 1.1). Particularly, in the Tropics it can also ensure the resilience of the poor and vulnerable groups (SDG1, Target 1.4) (Desa, 2018). Moreover, it has a role in the achievement of SDG 6 (Ensure availability and sustainable management of water and sanitation for all) by reducing water pollution and hazardous chemicals effluents in the water body (Target 6.3).

### **2.3.3 Environmental Impact**

The environmental impact of water hyacinth appears in the form of its effect on living and non-living organisms. Its absence or presence influences the ecosystem's goods and services. Figure 4 shows its effect on the provision, regulation, culture, and support of goods and services. As discussed in section 2.3, the counted environmental impact of water hyacinth in Ethiopia is low compared to Africa and the rest of the world. Provisioning is the most affected one associated with fresh water supply, seafood, and genetic resources. Fresh water supply is affected by its high water consumption (Chapungu et al., 2018; Churko, Nhamo, et al., 2023; Hill, 2003), evapotranspiration (Tewabe et al., 2017), and blockage of water flow (Ezama, 2019; Harun et al., 2021). According to (Arp et al., 2017), the weed causes high water loss which is likely to affect the water demand for household consumption and agricultural activities. From SDG perspective, the achievement of target 6.5 which deals with the implementation of water resource management and target 15.1 declares that sustainable use of water resources is doubtful.



**Figure 4.** Negative impact of water hyacinth on ecosystem goods and services across regions

Similarly, the weed cover change influenced the food provision by reducing fish population (Harun et al., 2021), feed shortage (Getahun and Kefale, 2023), and crop production (Enyew et al., 2020). Several studies also congruent that water hyacinth put distress on provisioning services, for instance, the diverse role of Lake Tana in Ethiopia (Bazie et al., 2022), the fish supply of Lake Victoria in Kenya (Kateregga and Sterner, 2009), and rice seed germination in India (Mathur and Mathur, 2018). It also affects the inland and aquatic genetic resources (Churko, Nhamo, et al., 2023; H. Getnet et al., 2021; Tewabe et al., 2017), particularly, native fish (Basaula et al., 2023; Ongore et al., 2018; Waithaka, 2013) and plant species (Maulidyna et al., 2021), invertebrate (Jones, 2009), and hippos (Coetzee et al., 2014). From the SDG perspective, this weed is a hurdle to achieving the production and productivity of agriculture, livestock, and fish (Target 2.3). Likewise, it can reverse the target of resilient agricultural activities (Target 2.4). Moreover, the effect of water hyacinth on the inland and aquatic genetic resources and biodiversity loss are against SDG 14 and target 15.5, respectively.

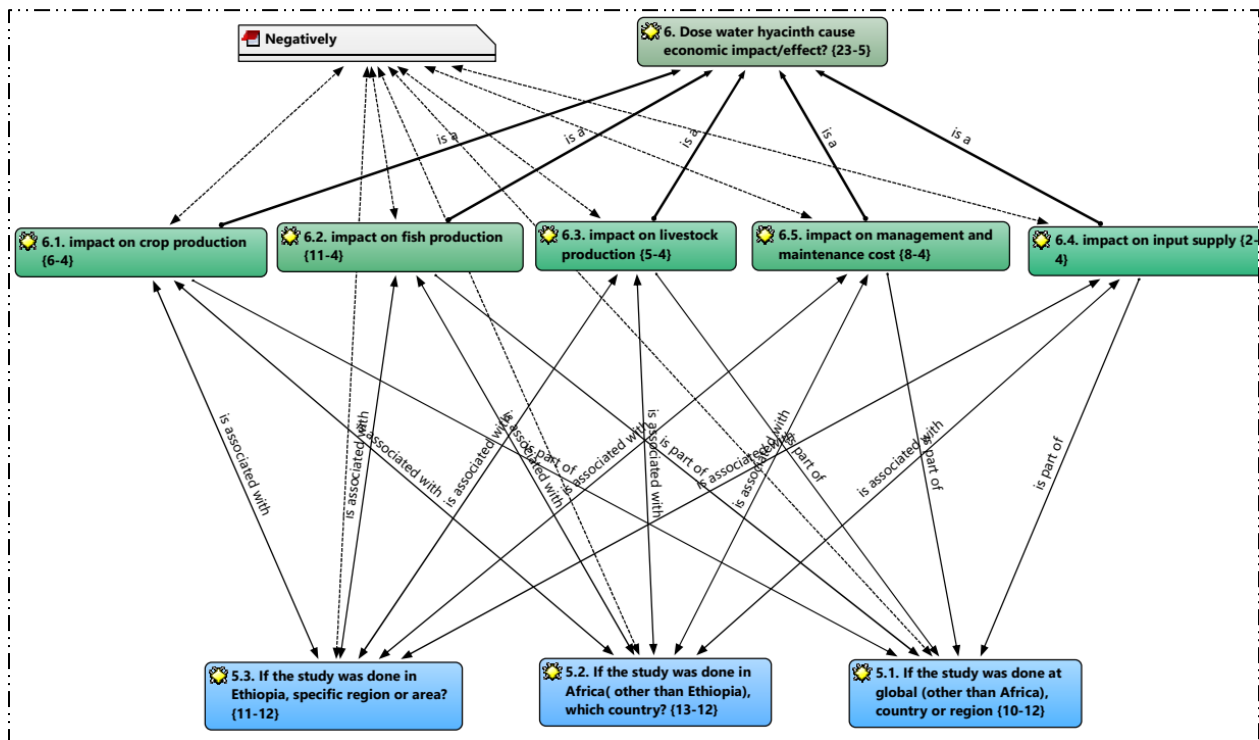
The detrimental regulation of the ecosystem process also appeared in the water body and the atmosphere. Accordingly, lethal gas production (Tewabe et al., 2017), methane emission (Oliveira Junior et al., 2021; Oliveira-Junior et al., 2017) reduced level of dissolved oxygen, sunlight blockage, and rise in water temperature (Getahun and Kefale, 2023) are among the effects of the weed. Furthermore, it creates a conducive environment for bacterial reproduction (Wang, 2021) and other waterborne diseases (Corman et al., 2023). In addition, the water regulation and purification process of the aquatic ecosystem is influenced by its invasion (Harun et al., 2021). In this regard, water hyacinth hinders the success of Target

6.6, which is to protect and restore water-related ecosystems as well as Target 6.3, which focuses on improving the water quality.

Recreational and cultural services like boating sail (Ingwani et al., 2010; Villamagna and Murphy, 2010) and aesthetic value (Dersseh, Melesse, et al., 2019) are the other environmental benefits disturbed by the weed. Conversely, it restricts the natural state of the river flow, swimming, as well as religious activity (Chapungu et al., 2018). Likewise, among support services, the nutrient cycle and primary production are also affected by this invasive weed. In Ethiopia, it affects the feed production (Getahun and Kefale, 2023; Tewabe et al., 2017) and nutrient cycle (Ingwani et al., 2010), whereas in other African countries, it reduced the level of oxygen in the water (Waithaka, 2013) and distracts the nutrient dynamics (Rommens et al., 2003a), which is against the SDG Target 12.2.

### 2.3.4 Economic Impact

As narrated in Figure 5, the economic impact of water hyacinth is linked to crop production, fish production, livestock production, input supply, and cost of management and maintenance. Section 2.3 discusses the impact of water hyacinth in three spatial cases. This section shows its economic impact in Ethiopia is high as compared to other African countries and the rest of the world.



**Figure 5.** Negative impact of water hyacinth on economic activities across regions

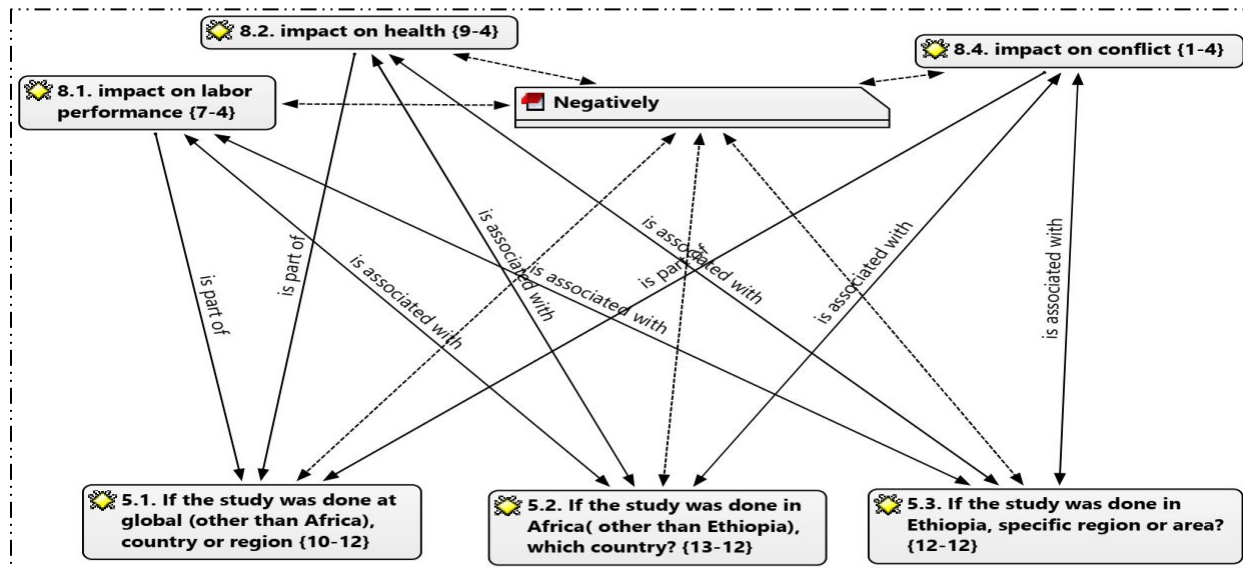
In Ethiopia, crop production is affected by the weed invasion in the crop field (Damtie et al., 2021; Enyew et al., 2020c), competes for water (Getahun and Kefale, 2023), and disturbed the production activity (Enyew et al., 2020b). Similarly, it has influenced the farmers' returns from crop production in other countries (Maulidyna et al., 2021). The impact of water hyacinth on crop production in Ethiopia is more noticeable as compared to other cases. Like crop production, the weed posed challenges in fishing activities. In Ethiopia, it has caused fish catch reduction (Enyew et al., 2020b; Tewabe et al., 2017) by making the fishing and the harvesting rate more tedious (Damtie et al., 2021; Dersseh, Melesse, et al., 2019; Hussien et al., 2020). In Africa, it affects the livelihood of farmers and traders associated with fish marketing (Segbefia et al., 2019) (PD2) by disordering the fishing business (Ezama, 2019; Ogunlade, 2002). Equally, this invasive weed caused a lack of access to fishing areas which resulted in increased cost of production and shortage of supply in the market (Villamagna and Murphy, 2010). Furthermore, its effect on livestock production and related activities is evident in Ethiopia. The grassland covered by the weed declines the grazing land (Tewabe et al., 2017), creates a shortage of feed supply (Enyew et al., 2020b), and caused death on livestock that used the weed as feed (Damtie et al., 2021). From the viewpoint of SDG Targets 2.3 and 2.4, the weed poses some barriers to the implementation of the SDGs by 2030.

The above-mentioned sources and other impacts discussed here invite additional costs of management and maintenance. As quoted in Figure 5, the costs to remove the weed from the farmland (Damtie et al., 2021; Getahun and Kefale, 2023a), the maintenance cost of blocked ditches and canals (Dersseh, Melesse, et al., 2019) (M. P. Hill, 2003), the costs associated with opening the blocked tunnel, and the reduced power generation due to insufficient volume of water (Dersseh et al., 2019; Ezama, 2019), and the additional cost of transportation due to limited boating access (Villamagna and Murphy, 2010). These costs are serious, particularly in Ethiopia and generally in Africa, as compared to other continents. The cost is exacerbated due to the lack of a strong invasive weed management policy, poor natural resource conservation practices, a lack of knowledge about the weed, and a lack of technology.

### ***2.3.5 Social Impact***

Figure 6 shows the social impact of water hyacinth regarding health, labor performance, and social conflicts. The negative impact is reported on labor performance, health, and social conflicts in the global situation, in Africa, and in Ethiopia. The performance of labor is affected in fishing and crop production activities. In Ethiopia, plowing is challenging in weed-infested areas (Getahun and Kefale, 2023; Tewabe et al., 2017) that need to spend a lot of time (Getahun and Kefale, 2023). On the other hand, people are displaced from fishing activities to other sectors where they perform well (Ogunlade, 2002). Similarly,

the time spent on catching fish has become longer due to blocked boat sail (Harun et al., 2021) and access to fishing grounds (Villamagna and Murphy, 2010). Certainly, the limited water supply as a result of blocked waterways brings conflict within the community (Harun et al., 2021).



**Figure 6.** Negative impact of water hyacinth on social affairs across regions

Its health impact is also reported as high in Ethiopia as compared to other African countries and globally. The weed exacerbates malaria transmission (Getahun and Kefale, 2023; Gezie et al., 2018), skin allergy (Enyew et al., 2020b), bilharzia (PD20), and several other human (Getahun and Kefale, 2023) and animal (Ingwani et al., 2010) diseases. Similarly, its health effect on the community (Honlah, Yao Segbefia, et al., 2019) is commonly narrated as a medium of expansion for mosquitoes (Chapungu et al., 2018). Globally, it creates a conducive environment for vector reproduction (Maulidyna et al., 2021), which transmit disease and disturb people’s comfort (Harun et al., 2021). So, it has imposed barriers to ending tropical and waterborne diseases as explained under the SDG Target 3.3.

## 2.4 Conclusion and Recommendations

Water hyacinth is an invasive plant alarmingly spread throughout the tropical region and around the world. Several studies have been done in varied disciplines regards its biology, relation to the environment, economic benefit and loss, its consequences on human wellbeing, and other issues related to this invasive weed. In all these aspects, information on positive and negative outcomes is generated in different parts of the world in disaggregated ways. Even though there are several literature reviews that have been done, they are hardly related to the Sustainable Development Goals (SDGs). The novelty of this paper lies in a systematic review that inspires its strength in addressing disaggregate articles focused

on the environmental, economic, and social impact of water hyacinth from different parts of the world to bring all findings into one picture. This assists the global intervention and national action to maximize the benefit and to halt the cost of water hyacinth through mobilizing knowledge, technology, and finance.

The articles reviewed here are mostly done after the ratification of SDG which are found in Ethiopia, other African countries, and globally. The review result indicates the global adverse effects of water hyacinth outweigh its benefits. Particularly, in Ethiopia its impact is high; specifically, the economic and social effect, as compared to other African countries and in the global arena. In other African countries, its impact on ecosystem services is high followed by the global level and Ethiopia, while the specific regulating service in the global context outweighs the other areas. The benefit of water hyacinth is narrated in terms of its role as input for the economic sector as well as its provisioning and regulating services as a remedy to sustain life and reduce pollution, respectively.

Most of the affected regions by water hyacinth are developing countries which are located along the tropics. Recalling its origin and expansion path, water hyacinth is an aggressive tropical weed that challenges the socio-economic and environmental aspects of the developing world. The cost of managing and utilizing this invasive weed is exacerbated due to a lack of strong invasive weed management policy, poor natural resource conservation practices, lack of knowledge, technology, and enough budget. Since its impact is not limited to the Tropical regions, an integrated effort needs to divert its severe consequences. In this respect, it is better to adopt the best global lessons, on the use of water hyacinth, as an opportunity to harness the threat.

Though water hyacinth is a global issue as well as a national challenge, these recommendations are made accordingly. In the Global arena, it is recommended to mobilize global resources such as knowledge, technology, finance, and innovation on agreed terms, promote the development and transfer of sustainable technologies to control and utilize water hyacinth, and develop partnerships across the tropical regions and share best lessons and practices to tackle the adverse effects of the weed. In the national context, our recommendation is focused on integrating invasive weed management strategy into the national and local planning and policies, adopting best lessons on how to use water hyacinth for income generation and environmental regulation, and implementing integrated soil and water conservation practices at water hyacinth prone areas.

## **Chapter 3: Dynamics Of Water Hyacinth in Ethiopia's Rift Valley: Trends, Status, and Future Prospects**

### **Abstract**

*This study analyzes the land-use and land-cover (LULC) changes in the Dembel and Koka catchments of Ethiopia, focusing on the impact of urbanization, agriculture, and invasive species, particularly water hyacinth. Results for the Dembel catchment indicate significant land-use transformations, with water bodies expanding, agricultural lands increasing substantially, and wetlands being overtaken by water hyacinth. Agricultural expansion and water hyacinth encroachment on wetlands and aquatic ecosystems are expected to persist, further exacerbating environmental pressures. The study demonstrated that from 1994–2024, Koka Lake's area fluctuated from 15,498.69 ha to 10,616.19 ha, reflecting environmental stress. Concurrently, water hyacinth coverage surged from 887 ha (1994) to 3,937.06 ha (2024), demonstrating aggressive invasion. Unlike Koka, Lake Dembel exhibited persistent hyacinth presence, with accelerated expansion post-2004 (2,120.5 ha by 2014). This rapid spread highlights severe ecological impacts, aligning with global invasive species trends. The findings suggest a direct correlation between urbanization, agricultural expansion, and the spread of invasive species, which threaten ecosystem stability and biodiversity in both catchments. The study emphasizes the need for integrated land management strategies to mitigate these impacts, particularly focusing on controlling invasive species and promoting sustainable agricultural practices. In conclusion, the study underscores the urgency for effective land-use planning and management to address the ecological challenges posed by urbanization, invasive species, and land degradation. Proactive measures and collaboration among policymakers, researchers, and local communities are essential to ensure the long-term ecological health and sustainability of these critical catchments.*

**Keywords:** Land-use change, Water hyacinth, Invasive species, Urbanization, Agricultural expansion and Ecosystem sustainability

### 3.1 Introduction

Water hyacinth is an invasive species that can quickly cover water bodies, upsetting ecosystems and human activities like fishing and transportation (Harun et al., 2021; Nega et al., 2022; Asmare, 2017). It is an invasive aquatic species that escaped from cultivation by 1900 (Lahon et al., 2023) and their rapid growth, adaptability, and resilience to severe environments make them difficult to control once established and impossible to eradicate (Gaikwad and Gavande, 2017). Rapid sexual and asexual reproduction of the water hyacinth has contributed significantly to its ability to spread throughout the world and create dense infestations (Gaikwad and Gavande, 2017). In just 6–14 days, the water hyacinth can double its biomass under the right circumstances (Sharma et al., 2020). Studies in India have shown that in just eight months, 10 plants can multiply into over 655,000, covering half a hectare (Datta et al., 2021).

The plant's rapid growth rate and ability to reproduce prolifically in a short time period has enabled it to spread to over 50 countries, primarily in the tropics and subtropics (Abba and Sankarannair, 2024). The weed's reproductive capacity allows it to rapidly cover wide areas of water bodies once introduced, making it difficult to control and necessitating early intervention before it becomes an entrenched problem (Cordeiro et al., 2020)

Water hyacinth thrives in nutrient-rich (eutrophic) waters, which promote its growth. Factors such as high levels of nitrogen and phosphorus from agricultural runoff or wastewater can significantly enhance its reproductive rates. Water hyacinth can adapt to varying environmental conditions, including changes in water levels and salinity. This resilience enables it to survive and reproduce in diverse habitats, further contributing to its spread. The key global hotspots of water hyacinth invasion include: Southeastern United States (Umat Lokman, 2022), Madagascar (Rakotoarisoa, 2017); Tropical Asia (India and Southeast Asia) (Lahon et al., 2023) and Lake Victoria in Uganda (Wanda et al., 2015). Its rapid growth and adaptability have led to widespread infestations, significantly impacting local and global ecosystems and economies (Summit, 2012)

In Africa, Water hyacinth was first recorded in Zimbabwe in 1937 and has since spread to various water bodies such as the Zambezi River, Lake Victoria, and the Shire River in Malawi (Navarro and George, 2000, Nyandoro, 2019; Kitunda, 2017). Its presence has been documented in multiple countries, leading to widespread infestations over the decades (Jernelöv, 2017b; Jernelöv, 2017a). Recent survey indicated that water hyacinth infestations are rapidly increasing across Africa, particularly in major river systems and lakes, causing severe ecological disruptions and affecting local community's livelihoods that depend on these water bodies. For example, it has severely affected fishing activities of Kenya, Uganda, and Tanzania among others (Lubembe et al., 2023a). The weed obstructs navigation and fishing routes,

leading to reduced fish catches and increased waterborne diseases like malaria and bilharzia due to stagnant water (Güereña et al., 2015; Gichuki et al., 2012; Villamagna and Murphy, 2010).

Water hyacinth was first observed in Ethiopia in 1956, specifically in Koka Lake and the Awash River, before spreading to adjacent water bodies (Firehun et al., 2014). From the late 1950s until late 2011, it was not considered a significant weed in water bodies in Ethiopia (Fessehaie, 2005). Over time, however, water hyacinth has proliferated throughout Ethiopia, including in Koka Lake, Lake Tana, Lake Ellen, Lake Abaya, Baro-Akobo River, and Awash River, posing substantial challenges to the utilization of these water resources (Firehun et al., 2014; Fessehaie, 2005). The trends and patterns of the proliferation of water hyacinth in Ethiopia, particularly in Lake Tana and the Rift Valley water bodies, brought significant ecological and socio-economic worrisome to the country (Tegene and Ayele, 2014; Dersseh et al., 2019). Since its official recognition in September 2011, water hyacinth has rapidly expanded in Lake Tana (Yirefu et al., 2019).

Numerous studies have been conducted on the various dimensions of water hyacinth in Lake Tana, Ethiopia. Just a few examples include the socioeconomic effects of water hyacinth on rural communities near Lake Tana (Damtie et al., 2022); a study on human health and water quality (Gezie et al., 2018); and the efficiency of remote sensing and machine learning in tracking invasive species (Belayhun and Mekuriaw, 2024). According to Enyew et al., (2020), the infestation of the plant has brought negative impact on local economies, transportation, and fishing, calling for immediate action in Lake Tana, northwestern Ethiopia. Other studies conducted in the lake Tana (Worqlul et al., 2020; Damtie et al., 2022; Dersseh et al., 2019; Tewabe, 2015) examined the effects of temperature and nutrient level on the infestation level, potential use and difficulties of biomass for bioenergy. Limited studies have looked at the trends and potential future uses of water hyacinth in Ethiopia as a whole.

Likewise, water hyacinth has recently proliferated in Ethiopia's Rift Valley waterbodies, raising serious ecological and economic concerns (Mengist and Moges, 2019). This invasive species has significantly impacted local biodiversity and water management systems by rapidly covering large areas of water, thereby disrupting aquatic ecosystems and impeding water flow (Yigermal and Assefa, 2019). The spread of water hyacinth in this region highlights the urgent need for effective management strategies to mitigate its adverse effects (B. B. Mengistu et al., 2017).

The objective of this study is, therefore, to map and analyze the distribution of water hyacinth in Lakes Koka and Dembel in Rift Valley, covering the last three decades (1994 to 2024). The study will offer thorough insights that will support the sustainable management of water hyacinth in Ethiopia's Rift Valley.

## **3.2 Methodology**

### **3.2.1 Data types and sources**

#### **Socio-economic**

With regard to socio-economic data, qualitative data from the local communities of Koka and Dembel catchment areas were collected. This qualitative information complemented spatial data sources and supported the researcher in getting insights into the local context, perspectives, and experiences of the communities. The combination of both spatial and qualitative data types enhanced the overall understanding of the area and helps to generate additional information that supports decision-making at different levels. Furthermore, focus group discussions (FGDs) and key informant interviews (KII) were conducted in which those who have a good background and experience in water hyacinth management were engaged, both for key informant interviews and focus group discussions held at Federal, Regional (Oromia region in Ethiopia), and District levels (Lume, Dugda, and Adami Tulu Jido Kombolch of East Shewa Zone of Oromia, Ethiopia) participated. The feedback and experiences shared during these sessions have also been invaluable in understanding the local context and validating the findings.

#### **Remote Sensing**

The present study utilized Landsat series satellite imagery as the primary data source. The study selected long-term datasets from Landsat due to their suitability for conducting trend analysis over extended periods, which is relevant to this research; despite their relatively lower spatial resolution compared to other satellite platforms (Refer Table 4). Landsat imagery spanning four decades (1994-2024) was acquired to align with local administrative reports of water hyacinth occurrences, which indicated that the weed was there on Koka Lake even before 1994, and its presence was reported on Lake Dembel since 2013.

Satellite images were systematically acquired using the JavaScript-based Google Earth Engine (GEE) platform, tailored to meet specific study objectives. For general land use and land cover change (LULCC) mapping and change detection, images captured during dry periods (January) were utilized. For the identification and mapping of water hyacinth, the study employed Landsat images acquired from September to October, extending into December and January. This time frame was specifically chosen because it coincides with the peak greenness and invasion period of water hyacinth, which typically occurs during the late wet season and early dry season (Gaurav et al., 2020). During these months, the vegetation is lush, making it easier to distinguish water hyacinth from other aquatic plants and features in the imagery. In addition, the seasonal variations in water levels can influence the distribution and visibility of water hyacinth, further supporting the selection of this temporal window for effective

monitoring (Dersseh et al., 2020). Using Landsat imagery during this critical period allows for more accurate assessments of the extent and health of water hyacinth infestations, which is essential for effective management and control strategies.

**Table 4.** Landsat 5 and 8, general information (USGS/Google).

S. N	Satellite	Sensor	Path	Row	Ground	Bands	Wavelength	Date of
1	Landsat-5	MSS and TM	168 and 169	54 and 55	30	B1	0.45 - 0.52 $\mu\text{m}$	27/01/1994 and 12/01/2024
						B2	0.52 - 0.60 $\mu\text{m}$	
						B3	0.63 - 0.69 $\mu\text{m}$	
						B4	0.76 - 0.90 $\mu\text{m}$	
						B5	1.55 - 1.75 $\mu\text{m}$	
						B6	10.40 - 12.50 $\mu\text{m}$	
						B7	2.08 - 2.35 $\mu\text{m}$	
2	Landsat-8	OLI/ <u>TIRS</u>	168 and 169	54 and 55	30	B1	0.43 - 0.45 $\mu\text{m}$	18/01/1994 and 14/01/2024
						B2	0.45 - 0.51 $\mu\text{m}$	
						B3	0.53 - 0.59 $\mu\text{m}$	
						B4	0.64 - 0.67 $\mu\text{m}$	
						B5	0.85 - 0.88 $\mu\text{m}$	
						B6	1.57 - 1.65 $\mu\text{m}$	
						B7	2.11 - 2.29 $\mu\text{m}$	
						B8	0.52 - 0.90 $\mu\text{m}$	
						B9	1.36 - 1.38 $\mu\text{m}$	
						B10	10.60 - 11.19 $\mu\text{m}$	
						B11	11.50 - 12.51 $\mu\text{m}$	

### 3.2.2 Land-use land-cover classification

#### Image pre-processing

The initial stage of image processing, referred to as image pre-processing, was conducted to ensure the quality and suitability of the collected images for subsequent analyses. This phase involved several critical steps aimed at enhancing the images and preparing them for accurate classification. These steps included cleaning to remove outliers, noise, and artifacts; applying noise reduction techniques; normalization processes; and feature extraction. Each of these processes was essential to mitigate

potential factors that could adversely affect the accuracy of image classification (Khanfar et al., 2017; Jiang et al., 2016).

In the context of processing Landsat imagery for land-use and land-cover mapping, as well as for analyzing water hyacinth distribution, a series of automated procedures was implemented using the Google Earth Engine (GEE) platform. This process included activities such as masking cloud and shadow pixels, correcting for bare-soil impacts, masking citrus areas, stacking layers to combine multiple spectral bands, mosaicking to create seamless composite images, clipping to define specific areas of interest, and extracting relevant features. All these operations were executed through code within the GEE environment, taking advantage of its robust computational capabilities and extensive library of satellite imagery (Gorelick et al., 2017; Chen et al., 2019).

The selection of Google Earth Engine (GEE) was driven by its comprehensive repository of satellite data and powerful cloud computing infrastructure, which together provide an ideal framework for identifying and mapping land-use and land-cover classifications, as well as change detection. The platform's advanced algorithms and machine learning functionalities enable efficient and accurate classification of water hyacinth in the Koka and Dembel catchments. Furthermore, GEE offers a wide array of spectral indices and data fusion techniques that enhance its analytical capabilities. Its user-friendly interface facilitates accessibility for users with varying levels of technical expertise, ensuring that researchers and practitioners can effectively harness the platform's capabilities for detailed environmental assessments and monitoring (Gorelick et al., 2017; Jiang et al., 2016).

### **Satellite image classification and post-processing**

In the study of image classification for mapping and quantifying water hyacinth, Lakes, and other land uses, the Random Forest Classification (RFC) (Zhu et al., 2018) algorithm was selected due to its notable advantages over other methodologies like Convolutional Neural Networks (CNNs) (LeCun et al., 2015) and Support Vector Machines (SVMs) (Cortes, 1995a) that can perform image classification.

Random Forest Classification (RFC) was chosen for several compelling reasons. First, RFC is recognized for its versatility and robustness, particularly when dealing with high-dimensional data, which is characteristic of satellite imagery used in mapping water hyacinth, lakes, and other land uses (Cutler et al., 2007). This versatility enables RFC to effectively manage the complex datasets typical in these analyses.

Unlike many other algorithms, RFC can handle noisy and incomplete data, a crucial feature when working with real-world satellite imagery that often contains errors or gaps (Liaw and Wiener, 2002). In

addition, RFC provides an inherent mechanism for assessing variable importance, which aids in understanding the contributions of different spectral bands and indices to classification outcomes. This feature is particularly useful in optimizing the classification process and enhancing interpretability (Stankowski and Parker, 2010). Overall, RFC's capabilities make it an ideal choice for accurately classifying water hyacinth and other land-use types in the study areas. The algorithm's ability to provide measures of feature importance is another significant advantage. This feature helps researchers and practitioners understand which variables are most influential in the classification process, enhancing interpretability and insight into the data.

Another advantage of RFC is its relatively modest requirement for training data. In water hyacinth, Lakes, and other land uses, where collecting extensive data can be challenging, RFC performs well even with smaller datasets (Cutler et al., 2007). This characteristic contrasts with Convolutional Neural Networks (CNNs), which typically require large volumes of data and significant computational resources to achieve high accuracy. While CNNs excel at learning complex spatial features and delivering detailed predictions, their reliance on extensive datasets and substantial computing power can make them impractical in resource-limited situations (LeCun et al., 1998).

Similarly, Support Vector Machines (SVMs) are effective in separating classes by optimizing a hyperplane in high-dimensional space. However, SVMs necessitate considerable manual feature extraction and are less efficient than RFC in scenarios requiring automated, high-dimensional feature extraction (Cortes, 1995). Furthermore, SVMs can be less effective when dealing with smaller datasets, which aligns with the challenges faced in the identification, mapping, and quantification of water hyacinth, lakes, and other land uses (Hsu, 2003). This further underscores the advantages of using RFC for the analysis in this study.

NDVI thresholds and object-based classification was used to separate hyacinth (high reflectance in NIR) from submerged macrophytes (e.g., *Ceratophyllum*). More importantly, we employed ground truthing via field surveys for confirmation.

In conclusion, RFC stands out as a particularly good choice when it comes to the requirements for mapping and quantifying land uses in large and diverse catchments like Koka and Dembel. As compared to CNNs and SVMs, it is a strong option due to its computational efficiency, ability to handle smaller datasets, and robustness to noisy data. RFC's interpretability and practical advantages make it a useful tool for the analysis of water hyacinth, lakes, and other land uses, even though CNNs and SVMs have their advantages in particular scenarios.

### 3.2.3 Land use Land Cover Change Computation

The Land-use Land-cover Change (LULCC) was quantified using an automated intersection method within ArcGIS geoprocessing tools. This methodological approach involved applying a specific formula (refer Formula 1) to assess changes in land-use and land-cover over time, taking into account both gains (represented by a positive sign) and losses (represented by a negative sign) in different landuse and land cover categories. The intersection method in ArcGIS spatially overlays two or more datasets, allowing for the calculation of changes between them based on their spatial extent and attributes. This analytical process provides a detailed understanding of how land-use and land-cover have evolved and shifted spatially, supporting comprehensive assessments of environmental and urban changes.

$$\Delta LULC \text{ of Year}(x) = [LULCC^*i] \pm [LULCC^*f] \quad 3.1$$

Where,  $\Delta LULC$  is Change in Land use Land cover,  $LULCC^*i$  is Land use Land cover classification of initial year and  $LULCC^*f$  is Land use Land cover classification of final year.

The standard color selection and usage was considered while mapping of the Land use Land cover and change in this study.

### 3.2.4 Accuracy assessment

Image classification is a popular technique for extracting features from remotely sensed data for mapping purposes. However, this method is only effective when accuracy is evaluated. Consequently, a thirty percent validation data set based on ground truthing, and reference background GEE satellite view maps was used to assess accuracy in this study. The fully automated GEE platform, which is based on Scrip was used to assess accuracy. The User's Accuracy (UA) reliability lies in the likelihood that the pixels on the classified image truly match the ground truth.

$$A = \frac{\text{Total number of correct pixels in a category}}{\text{Total number of pixels of that category derived from the reference data}} \quad 3.2$$

The image classification accuracy that termed as accuracy on which the chance that any pixel correctly classified on image known as Producer Accuracy (PA) and

$$PA = \frac{\text{Sum of all reliability figures in reliability row}}{\text{Total number of categories in the test set}} \quad 3.3$$

The proportion of pixels correctly classified, or it is the combined accuracy of the map for all classes that is the Overall Accuracy (OA)

$$OA = \frac{\text{Sum of the diagonal elements}}{\text{Total number of accuracy sites (pixels)}} \quad 3.4$$

Another widely used accuracy assessment for image classification is the Kappa Statistic or Coefficient that measures classification accuracy from an error matrix by using a discrete multivariate approach. It works in off-diagonal elements and was incorporated as a product of the row and column marginal totals and its value ranges from 0 to 1 (Table 5).

$$K_{hant} = \frac{(\mathbf{Obs} - \mathbf{exp})}{(1 - \mathbf{exp})} \quad 3.5$$

where =  $K_{hant}$  is the Kappa coefficient,  $\mathbf{Obs}$  is the observed correct, it represents the accuracy reported in error matrix (overall accuracy), and  $\mathbf{exp}$  represents the expected correct, which represents correct classification (Rwanga and Ndambuki, 2017).

**Table 5.** Kappa Statistic value and its interpretation

No	Kappa Statistic Value	Agreement strength
1	$\leq 0$	No agreement
2	0 – 0.2	Slight agreement
3	0.21 – 0.4	Fair agreement
4	0.41 – 0.6	Moderate agreement
5	0.61 – 0.8	Substantial agreement
6	0.81 – 1.00	Almost perfect agreement

### ***3.2.5 Summary: Steps and procedures of data collection and analysis***

The study utilized Landsat-5 TM and Landsat-8 OLI datasets, ground truth data from GPS ground surveys, and socio-economic data. A supervised image classification method, specifically Random Forest Classification (RFC), was implemented on the Google Earth Engine (GEE) platform, which supports JavaScript coding. The accuracy of the image classification was assessed using overall accuracy (OA) (Story and Congalton, 1986), user accuracy (UA) (Rwanga and Ndambuki, 2017b), and producer accuracy (PA) (Stehman and Foody, 2009), along with the kappa statistics. Various software applications, including ArcGIS, QGIS, were utilized for different analyses in this research.

### 3.3 Results and Discussion

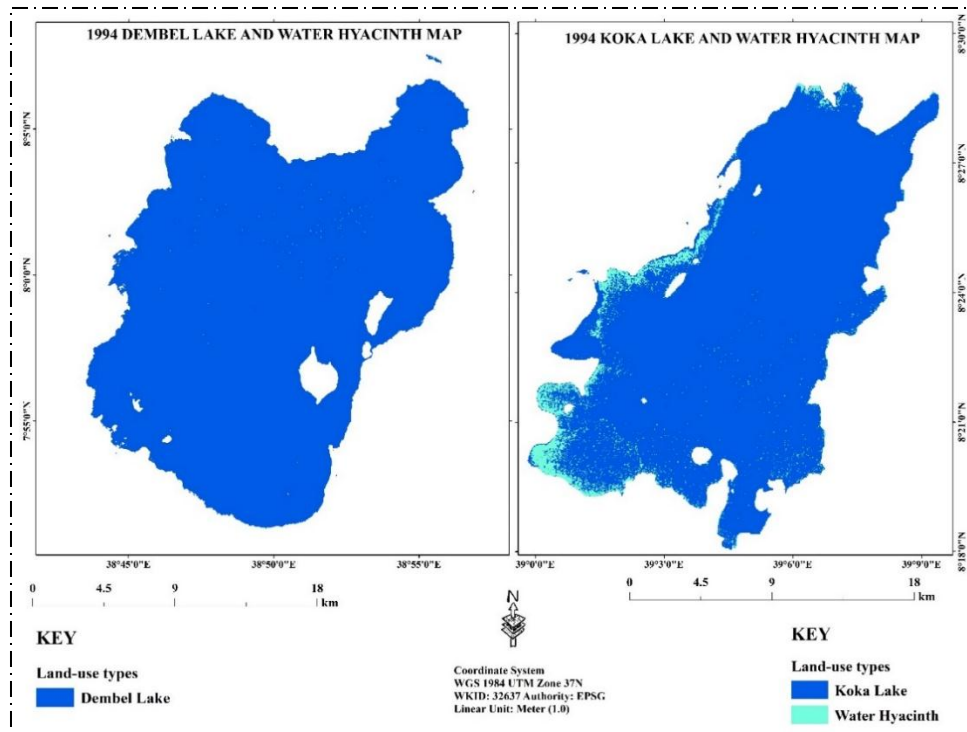
#### 3.3.1 Trend of Water Hyacinth over Four Decades

Table 6 presents the data on Dembel and Koka Lakes, including the water hyacinth invasion over these lakes for four consecutive decades from 1994 to 2024. The coverage of Dembel Lake successively decreased over these four decades, from 41,290.56 hectares in 1994, to 41,343 hectares in 2004, 37,896 hectares in 2014, and 36,685 hectares in 2024. On the other hand, water hyacinth was not present in Dembel Lake during the first two decades covered by the study, but its coverage increased successively in the later years, reaching 3,682.02 hectares in 2014 and 5,442.91 hectares in 2024 (Figures 7, 8, 9, and 10).

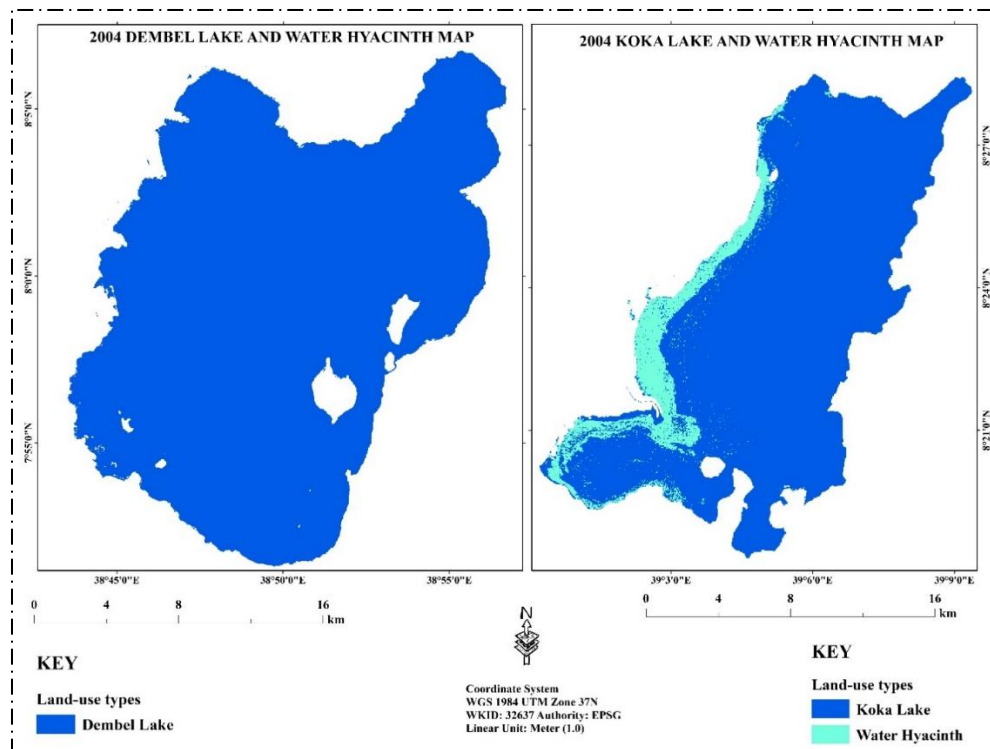
**Table 6.** Dembel and Koka Lakes and Water Hyacinth coverage (ha) for 1994 to 2024

Lakes and Hyacinth	1994	2004	2014	2024	Remark
Dembel Lake	41,290.56	41,343.15	37,896.98	36,685.34	Decreased
Water Hyacinth	0.00	0.00	3,682.02	5,442.91	Increased
Koka Lake	15,498.69	11,868.83	12,419.39	10,616.19	Decreased
Water Hyacinth	887	1,354.68	3,120.05	3,937.06	Increased

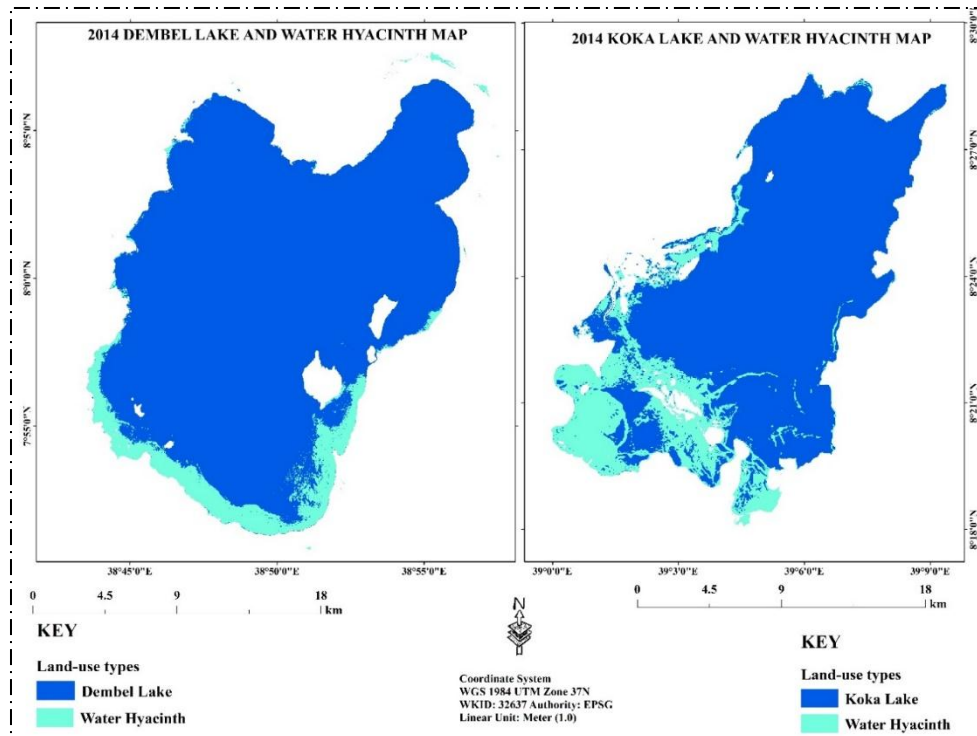
In a similar vein, Table 6 illustrates the expansion of water hyacinth and its encroachment in Koka Lake over a span of four 10-year periods from 1994 to 2024. The lake's coverage initially showed a decline in the first two decades, dropping to 15,498.69 hectares in 1994, 11,868.83 hectares in 2004, and then rebounding to 12,419.39 hectares in 2014. However, by 2024, the lake's coverage had once again decreased to 10,616.19 hectares. As compared to Lake Dembel, Koka Lake experienced water hyacinth invasion in 1994, its areal coverage reaching 887 hectares in the first decade and extending to 1,354.68 hectares in the second decade. The growth of water hyacinth was particularly rapid in the latter two decades, with areal coverage reaching 3,120.05 hectares in 2014 and 3937.06 hectares in 2024.



**Figure 7:** Water Hyacinth over Dembel and Koka Lakes for 1994



**Figure 8.** Water Hyacinth over Dembel and Koka Lakes for 2004



**Figure 9.** Water Hyacinth over Dembel and Koka Lakes for 2014

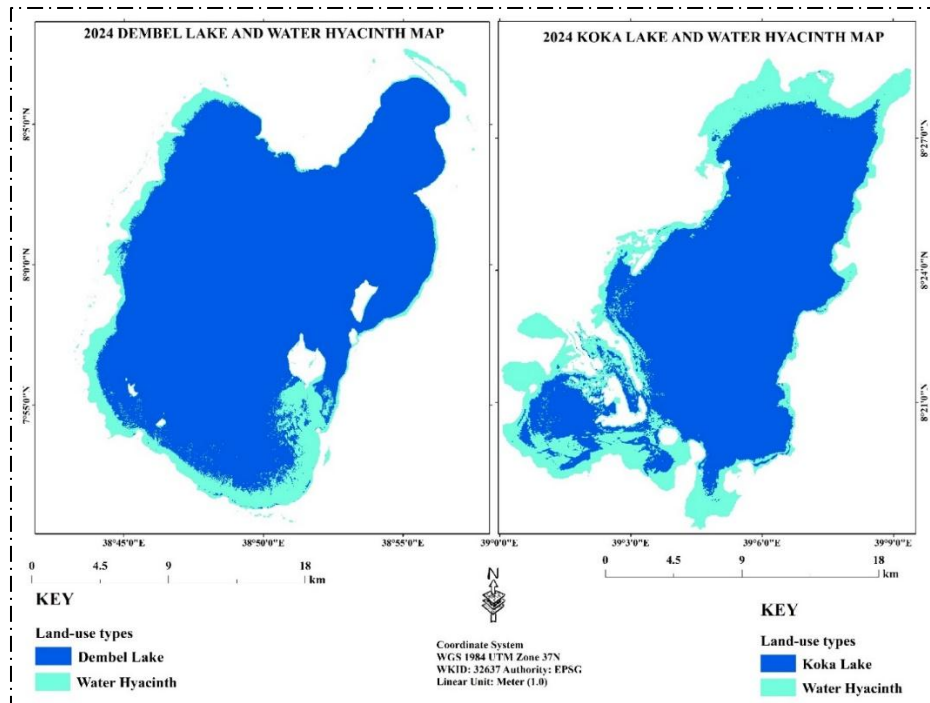
### 3.3.2 Current State of Water Hyacinth

Lake koka is an artificial lake created by the reservoir of Koka Dam that was constructed in the 1950 with water from the Awash and Mojo Rivers. Whereas Lake Dembel is a natural Lake, filled with water from the Katar and Meki Rivers. Both lakes have faced water hyacinth invasion for over two decades, causing significant ecological, economic, and social impacts.

At present, over 5,442.91 ha of Lake Dembel is covered by water hyacinth, whereas the area covered by the invasive weed water hyacinth in Lake Koka spans 3,937.06 hectares (Table 6 and figure 14). In the year 2024, the spatial analysis of water hyacinth and land activities in both lakes shows notable differences compared to past years, underscoring continuous environmental transformations and difficulties in managing these areas

The increase in water hyacinth indicates a significant strain on the environment, probably affecting the quality of water and the variety of life in water bodies, in line with research by Bell et al., (2012) and Churko et al., (2023), which have shown the negative impacts of water hyacinth on water ecosystems.

This continuous increase highlights the persistent challenges in controlling this invasive plant, as pointed out by Kuma et al., (2022) and (Mengesha, n.d.), who have connected water hyacinth to decreases in water biodiversity and changes in the functions of ecosystems.



**Figure 10.** Water Hyacinth over Dembel and Koka Lakes for 2024

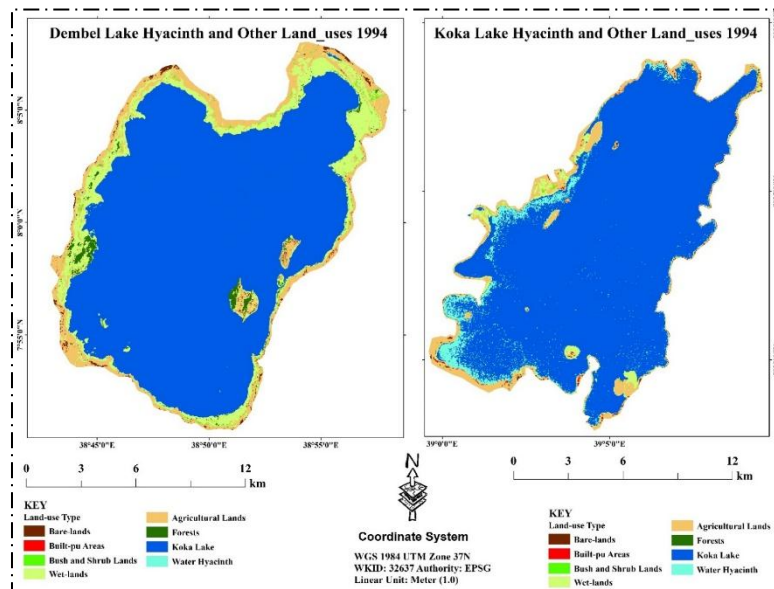
### 3.3.3 Water Hyacinth and Other Land Uses in Dembel and Koka Catchments 1994

In 1994, an analysis of land cover and the assessment of the presence of water hyacinth revealed significant differences between Lake Dembel and Lake Koka. Lake Dembel spans a total area of 41,290.56 hectares in 1994, its catchment predominantly covered by wetlands (5,453.44 hectares) and agricultural lands (3,923.43 hectares). The forested areas in Lake Dembel amount to 1,632.58 hectares. Notably, water hyacinth was absent in Lake Dembel in 2004, indicating the absence of this invasive species at that time. This observation aligns with findings from studies that have reported varying levels of water hyacinth infestation across different lakes (Afuye et al., 2024).

In 1994, Lake Koka covers a total area of 15,498.69 hectares. In 2004, it experienced a significant infestation with water hyacinth, which covered 1,354.68 hectares. The remaining land cover in Lake Koka catchment included 1,183.46 hectares of agricultural lands and 475.02 hectares of wetlands. This infestation underscores the substantial impact of water hyacinth on aquatic environments, as it has been documented to reduce biodiversity and affect water quality (Kindu et al., 2022).

The absence of water hyacinth in Lake Dembel in 1994 and 2004 and its substantial coverage in Lake Koka in these two periods highlight a critical contrast in the impact of this invasive species. Lake Dembel's extensive wetlands, agricultural lands, and forested areas underscore its diverse land use, while

Lake Koka's smaller wetland area and significant presence of water hyacinth point to challenges in managing aquatic health and biodiversity (figure 11).



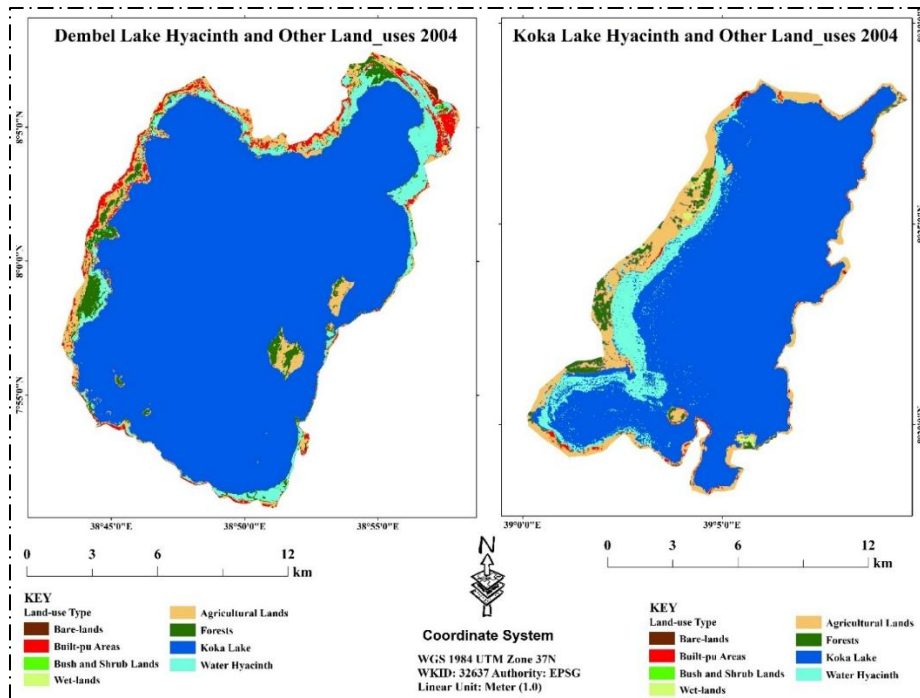
**Figure 11.** Dembel and Koka Hyacinth and other Land-uses 1994

### 3.3.4 Water Hyacinth and Other Land Uses for Dembel and Koka Catchment 2004

The comparison of land cover and the presence of water hyacinth in Lake Dembel and Lake Koka for the year 2004 reveals distinct differences in their environmental conditions and ecological health.

The presence of water hyacinth in Lake Koka is particularly concerning. Covering 1,354.68 hectares, this invasive species poses serious threats to aquatic ecosystems. Water hyacinth is known for its rapid proliferation and detrimental effects, including reduced biodiversity and impaired water quality. Studies confirm that water hyacinth can significantly alter ecosystem functions and decrease aquatic life diversity (Harun et al., 2021; Rocha-Ramírez et al., 2014). The substantial coverage of water hyacinth in Lake Koka reflects a severe infestation that aligns with observed impacts reported in other research (Kuma et al., 2022; Mengesha, n.d.).

Lake Dembel's land cover is characterized by a predominance of water bodies, whereas Lake Koka's water body area is relatively smaller and overshadowed by the significant presence of water hyacinth. This suggests that Lake Dembel supports a more extensive aquatic habitat. In addition, Lake Dembel's wetlands are much larger (5,453.44 hectares) compared to Lake Koka's (475.02 hectares), highlighting a more robust wetland presence in the Dembel watershed. Wetlands are crucial for ecological balance and biodiversity (Verhoeven et al., 2006; Wang et al., 2008) (Fig. 12).



**Figure 12.** Dembel and Koka Hyacinth and Other Land-uses 2004

### 3.3.5 Water Hyacinth and other Land-Uses Dembel and Koka Catchment 2014

In 2014, the spatial distribution of land cover and the presence of water hyacinth for Lake Dembel and Lake Koka exhibited notable patterns. Lake Dembel encompassed a total land area of 37,896.98 hectares. During this period, the lake experienced a significant infestation of water hyacinth, covering 3,682.02 hectares. This increase reflects a continuing problem with this invasive species, aligning with earlier data indicating its expansion. The persistence of water hyacinth in Lake Dembel highlights its growing impact on aquatic ecosystems, consistent with findings from studies on aquatic invasions (Santos et al., 2011; Ageng'o, 2013).

In terms of other land uses, Lake Dembel's coverage included 5,453.44 hectares of wetlands, 3,923.43 hectares of agricultural lands, and 1,632.58 hectares of forest areas. This distribution illustrates a diverse land-use profile, with significant wetland and agricultural areas that play crucial roles in the lake's ecological balance. The wetlands, in particular, remain a critical feature for maintaining biodiversity and supporting various ecological functions (Neubauer and Craft, 2009).

Conversely, Lake Koka, with a total land cover of 12,419.39 hectares, also faced a substantial water hyacinth presence, covering 3,120.05 hectares. This continued increase underscores the lake's ongoing

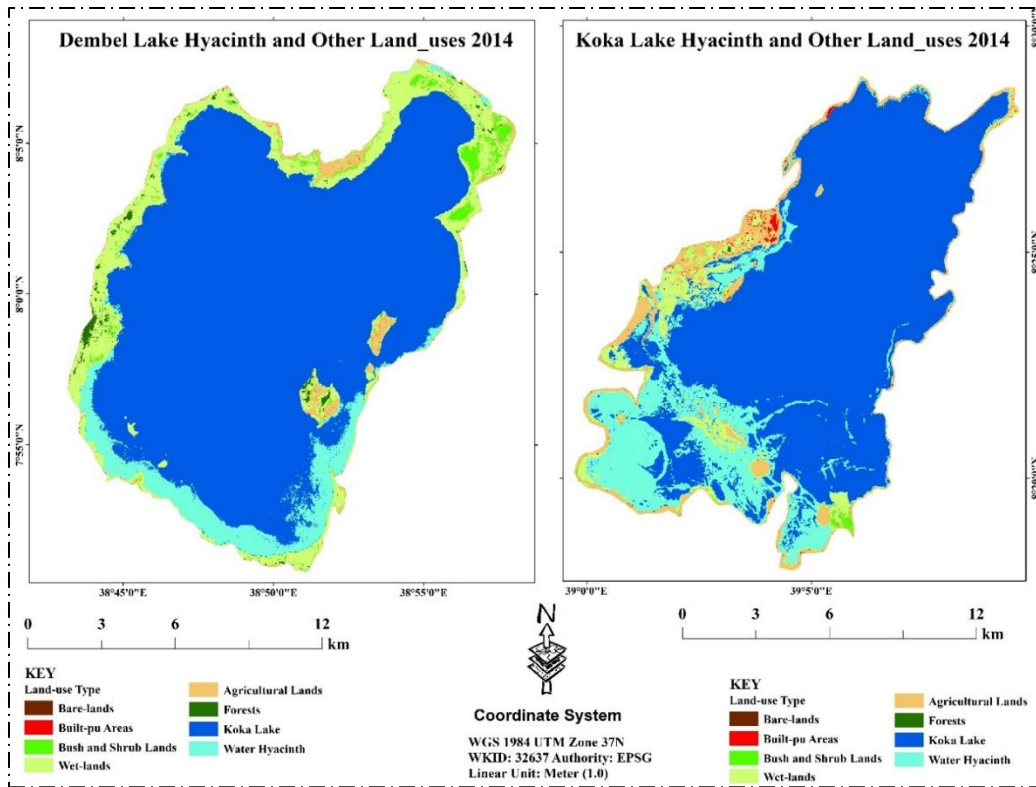
struggle with this invasive species, which has been linked to adverse effects on water quality and ecosystem health (Lubembe et al., 2023a).

In 2014, the land cover of Lake Koka was primarily composed of 1,183.46 hectares of agricultural lands and 475.02 hectares of wetlands. While agricultural lands and wetlands constitute a smaller proportion of Lake Koka's land use compared to Lake Dembel, they are still essential for understanding the lake's ecological dynamics.

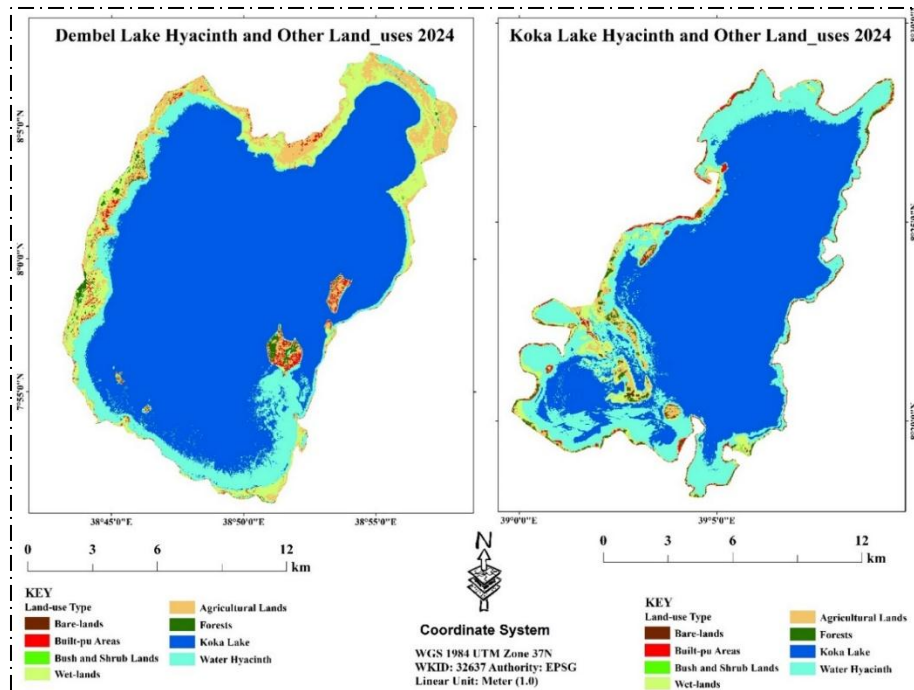
Overall, the 2014 data highlight a persistent and growing problem of water hyacinth in both lakes. The increasing coverage of this invasive species in Lake Dembel and Lake Koka points to significant ecological challenges that need to be addressed. The diverse land uses in Lake Dembel and the ongoing land cover change in Lake Koka reflect varying impacts and management needs for these aquatic ecosystems.

The comparison of these two lakes reveals a stark contrast in the distribution and impact of water hyacinth. Lake Dembel, with its extensive aquatic habitat and significant water hyacinth coverage, faces greater challenges in managing this invasive species compared to Lake Koka. The substantial rise in water hyacinth in both lakes underscores the need for urgent management strategies to address its spread and mitigate its impacts on aquatic ecosystems. Research has consistently demonstrated that water hyacinth poses significant threats to aquatic ecosystems by disrupting native species, altering nutrient cycling, and affecting water quality (Kochi et al., 2020)

In summary, the data from 2014 highlights a troubling increase in water hyacinth coverage in both Lake Dembel and Lake Koka. This expansion poses significant ecological challenges, emphasizing the need for effective management and intervention to preserve water quality and biodiversity. The ongoing shifts in land use and the continued rise of water hyacinth reflect broader trends in ecological change and underscore the importance of addressing invasive species in aquatic environments (figure 13).



**Figure 13.** Dembel and Koka Hyacinth and Other Land-uses 2014



**Figure 14.** Dembel and Koka Hyacinth and Other Land-uses 2024

### 3.3.6 Koka Lake and Water Hyacinth Invasion (1994 – 2024)

Table 6 provides a detailed overview of the extent of water hyacinth invasion in Koka Lake over 30 years, from 1994 to 2024. The land cover of Koka Lake experienced notable fluctuations throughout these decades. In 1994, the lake's total area was 15,498.69 hectares. By 2004, the coverage had decreased to 11,868.83 hectares. However, in 2014, the lake's coverage slightly increased to 12,419.39 hectares, indicating a recovery period. Unfortunately, this positive trend was short-lived, as, by 2024, the lake's coverage had decreased again to 10,616.19 hectares. This overall decline mirrors trends observed in other studies of lake areas undergoing environmental stress and anthropogenic impacts (Carneiro et al., 2022; Neves et al., 2020).

In contrast to the patterns observed in Dembel Lake, water hyacinth was present in Koka Lake from the start of the observation period. The initial coverage in 1994 was 887 hectares, which increased to 1,354.68 hectares by 2004. The spread of water hyacinth accelerated significantly in the subsequent decades. By 2014, the coverage had expanded to 2120.5 hectares and continued to increase dramatically, reaching 3937.06 hectares by 2024. This rapid expansion underscores the aggressive nature of water hyacinth and its detrimental effects on aquatic ecosystems. Studies have consistently shown that water hyacinth can severely impact water quality, biodiversity, and the ecological balance of affected water bodies (Fessehaie, 2005).

The contrasting patterns between Koka and Dembel Lakes highlight the varying impacts of water hyacinth invasion and land cover changes. While Dembel Lake experienced a significant increase in water hyacinth only in the latter decades, Koka Lake faced an ongoing invasion that escalated over time. These findings illustrate the complex interactions between invasive species and environmental changes, stressing the need for targeted management strategies to address these challenges effectively (Damtie, Berlie, Gessese, et al., 2022b).

### 3.3.7 Land use land cover of Dembel and Koka Catchments

#### 3.3.7.1 Land Use and Land Cover Dembel (1994–2024)

Table 7 and Figure 15 present the general land use and land cover for both Dembel and Koka catchment from the year 1994 to 2024. Over the past 30 years, the Dembel area has experienced significant land use and land cover transformations, reflecting broader environmental, social, and economic changes.

Water bodies have steadily declined from 41,290.56 hectares in 1994 to 36,685.34 hectares in 2024. This reduction, likely due to water extraction and climatic pressures, is accompanied by a troubling rise in

water hyacinth a species which was absent in earlier years signalling an ecological disturbance in aquatic environments. The reduction of water bodies from 41,290.56 ha in 1994 to 36,685.34ha in 2024 suggests significant hydrological stress, likely exacerbated by water abstraction for agriculture, industrial use, and climate variability. This trend aligns with findings from Tesema et al. (2022) in the Ethiopian Rift Valley, where lake shrinkage was linked to declining rainfall and unsustainable irrigation. Moreover, the resurgence of wetlands after a period of decline may be indicative of ecological restoration efforts or a response to reduced anthropogenic pressure, as observed by Dixon et al., (2021) in similar wetland environments.

Wetlands initially shrank by almost half by 2014 but have partially recovered by 2024, possibly due to natural regrowth or restoration efforts. Meanwhile, built-up areas have expanded nearly fourfold, highlighting rapid urbanization and infrastructural growth.

Cultivated croplands have increased gradually, indicating communities' dependence on agricultural activities. However, this expansion appears to have come at the cost of forests, which have shrunk by more than 65%, and bushland, which peaked in 2014 before a steep decline by 2024, suggesting land conversion and degradation. Bare lands, once widespread, have dramatically decreased, likely due to reclamation or land cover change. The increase in cultivated land demonstrates a growing dependence on agriculture, consistent with Ethiopia's national policy, which emphasizes agricultural intensification. However, this has come at a high ecological cost most notably, by >65% reduction in forest cover. This pattern is echoed in the highlands of Ethiopia where forest loss is often driven by subsistence farming and fuelwood extraction (Yadeta et al., 2022; Adugna, 2022). The decline in bush-land and forests is a concerning indicator of biodiversity loss and ecosystem service reduction.

The spread of water hyacinth, now covering over 3937.06 ha, represents a significant ecological disturbance. Similar infestations in Lake Tana and other Ethiopian water bodies have been attributed to nutrient loading and eutrophication, driven by agricultural runoff and urban waste (Ayele and Atlabachew, 2021). The absence of this invasive species in earlier years but its rapid growth by 2024 is alarming reavels ecological imbalance and water quality degradation.

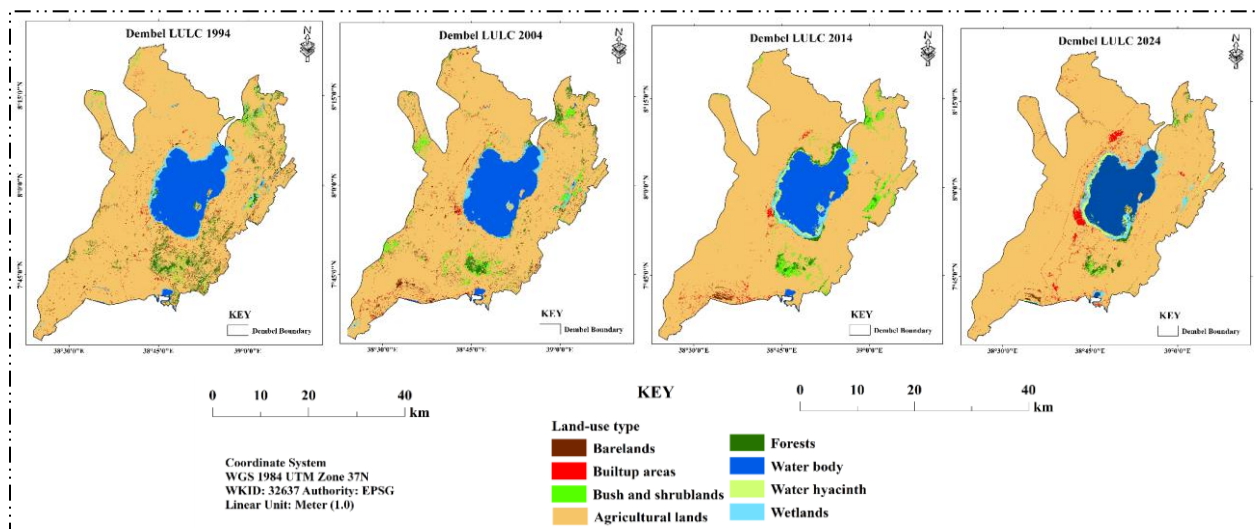
The fourfold increase in built-up areas underscores rapid urbanization, a phenomenon extensively documented in Ethiopian peri-urban regions (Aticho et al., 2023). While this reflects economic development and population growth, it also signals the displacement of natural land covers, leading to habitat fragmentation and increased surface runoff, as shown by (Usman et al., 2023) in outskirts Addis Ababa.

Interestingly, the decline in bare lands suggests some positive land cover changes, potentially due to land reclamation, afforestation, or natural vegetation regrowth. This may reflect the impact of government-led land rehabilitation programs such as the Sustainable Land Management Program (SLMP), which has shown success in restoring degraded lands (Abera et al., 2020).

In summary, Dembel’s landscape is shifting from natural ecosystems toward human-dominated land uses. While agricultural and urban expansion reflects development, they also raise concerns about sustainability, biodiversity loss, and the need for better land management strategies.

**Table 7.** Summary of Dembel General LULC Classification Results

Land-use Type	1994	2004	2014	2024
	Area in ha	Area in ha	Area in ha	Area in ha
Water Body	41,290.56	41,343.15	37,896.98	36,685.34
Water Hyacinth	0.00	0.00	3,682.02	5,442.91
Wetlands	8,061.13	4,900.53	4,461.52	6,967.65
Built-up Areas	1,889.92	2,737.76	2,992.09	7,252.58
Croplands Cultivated	277,784.11	280,889.05	288,240.54	291,548.25
Forests	10,465.98	7,178.15	4,649.15	3,588.01
Bush and shrub Lands	4,274.84	7,080.32	9,514.88	948.16
Bare lands	7,509.18	7,124.56	827.52	772.24



**Figure 15.** Dembel General LULC Classification Maps for 1994 to 2024

### 3.3.7.2 Land Use and Land Cover Change in Koka (1994–2024)

Over the past 30 years, Koka has experienced steady changes in land use and land cover, reflecting increasing human activity and ecological pressure.

Water bodies have declined significantly from over *15498.69 ha in 1994* to just *10616.19 ha in 2024*, indicating shrinking lake and river systems, likely due to reduced inflow, sedimentation, and climatic shifts. The reduction of Koka's water bodies from approximately 15498,69 ha in 1994 to *10616.19 ha in 2024* represents a nearly 31% loss, signaling declining hydrological health. This trend aligns with research from the Central Rift Valley of Ethiopia, where increasing sedimentation, agricultural runoff, and altered precipitation patterns exacerbated by climate change are leading to lake shrinkage (Usman et al., 2023; Keraga, 2019). The problem is further compounded by upstream water extraction, which alters natural flow regimes.

In contrast, water hyacinth, an invasive species, has more than tripled, expanding from 887 ha in 1994 to 3937.06 ha, further threatening aquatic ecosystems. The tripling of water hyacinth from 887ha to 3937.06 ha illustrates a growing ecological crisis. Water hyacinth (*Eichhornia crassipes*) has been identified as a significant invasive threat across Ethiopian water bodies, including Lakes Koka, Tana, and Ziway, where it impedes water transport, reduces biodiversity, and depletes dissolved oxygen (Churko, Nhamo, et al., 2023c). Its rapid expansion in Koka is symptomatic of nutrient enrichment from urban and agricultural sources, consistent with eutrophication studies in the region.

Wetlands have fluctuated, initially declining but showing a mild recovery in 2024, hinting possible restoration or natural regeneration. Meanwhile, *built-up areas* have grown by over 80%, from *1,516 ha to 2,763 ha*, highlighting on-going urbanization and infrastructure development.

*Cultivated croplands*, which dominate the region, have expanded modestly from *113,968 ha to 119,407 ha*, reinforcing the area's continued reliance on agriculture. However, this agricultural pressure comes at the expense forest land which have been reduced by two-thirds, shrinking from *3,883 ha in 1994* to just *1,273 ha in 2024*, a clear sign of deforestation. Similarly, bush/shrub lands and bare lands have steadily declined, likely converted to croplands or settlements, reducing natural vegetation cover and open land availability. The modest expansion of croplands (from 113,968 ha to 119,407 ha) indicates steady agricultural intensification. While this supports food security and livelihoods, it often results in the conversion of forests and natural vegetation. The drastic forest loss (a ~67% reduction) reflects the trade-off and aligns with studies showing how agricultural expansion is a primary driver of deforestation in the

Ethiopian highlands (Boespflug, 2024). This deforestation has implications for carbon storage, biodiversity, and watershed health (Table 8).

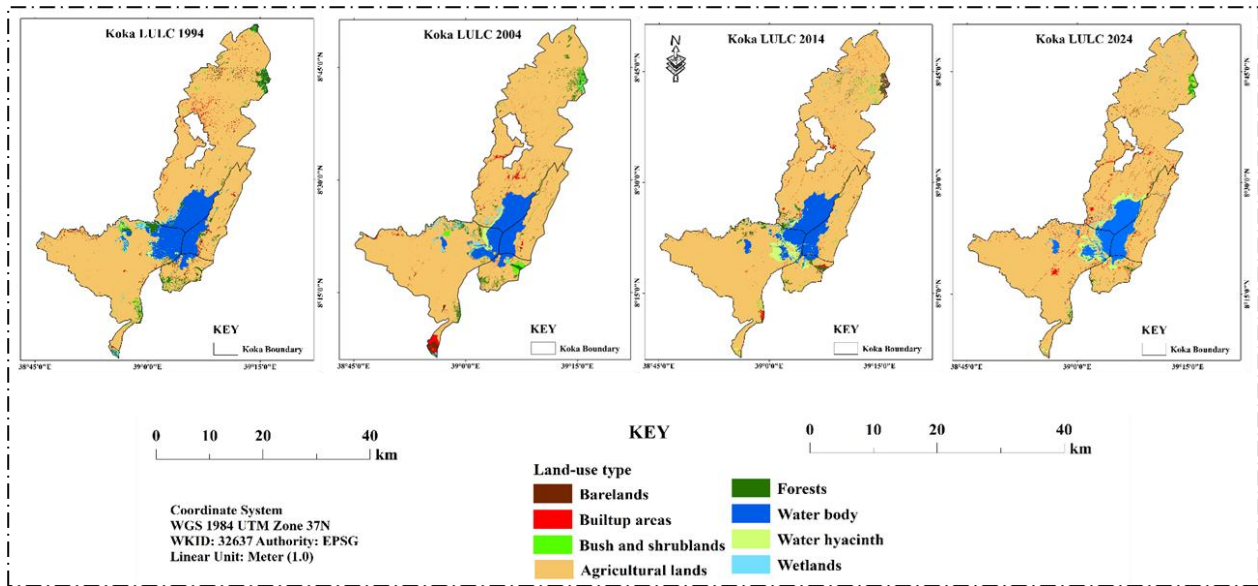
The increase in built-up areas by over 80% reflects ongoing urban sprawl and infrastructure expansion. As documented in similar peri-urban environments in Ethiopia (Molla et al., 2024). Such changes typically result in the encroachment of urban land into fertile agricultural and forested lands, leading to increased land use shift and habitat loss. This trend also suggests increased population pressure and economic shifts towards urban livelihoods.

Declines in bush/shrub and bare lands suggest increased pressure on remaining open lands, likely driven by their conversion into croplands or residential areas. This process reduces ecological buffers and contributes to landscape homogenization, making ecosystems more vulnerable to degradation and climate variability (Sitotaw, 2025).

In summary, Koka’s landscape is steadily shifting toward greater human use, especially agriculture and urban development, while natural ecosystems like forests, wetlands, and open water bodies are declining. These trends underscore the need for proactive land-use planning and ecosystem protection to maintain environmental balance in the region.

**Table 8.** Koka General LULC Classification Results

Land-use Type	1994	2004	2014	2024
	Area in ha	Area in ha	Area in ha	Area in ha
Water Body	15,498.69	11,868.83	12,419.39	10,616.19
Water Hyacinth	887	1,354.68	3,120.05	3,937.06
Wetlands	1,678.86	1,255.93	1,068.14	1,356.62
Built-up Areas	1,515.91	1,735.90	1,937.16	2,763.27
Croplands Cultivated	113,968.05	118,641.27	118,769.46	119,407.01
Forests	3,883.36	3,584.96	1,578.47	1,272.68
Bush and shrub Lands	1,144.44	1,139.31	977.98	591.03
Bare lands	1,641.25	1,233.09	779.41	589.65



**Figure 16.** Koka General LULC Classification Maps for 1994 to 2024

### 3.3.8 Land use land cover change

This report presents a comparative analysis of Land Use/Land Cover (LULC) changes in the *Dembel* and *Koka* study areas over a ten-year period (2014–2024). Using LULC transition matrices, the total *gains*, *losses*, and *net changes* for major land cover categories were derived to understand spatial dynamics and trends affecting the landscapes.

#### 3.3.8.1 *Dembel Land cover change Loss-gain Matrix*

Figure 17 and Table 9 below present the LULC change matrix showing total gains and losses from 2014 to 2024 for the Dembel watershed. Between 2014 and 2024, the Dembel region experienced substantial land use and land cover (LULC) transformations, primarily driven by urban growth, agricultural expansion, and ecological change. Built-up areas increased by approximately 4,254 hectares, reflecting rapid urbanization likely spurred by population growth, infrastructure development, and possibly resettlement programs. This expansion aligns with broader patterns of unplanned peri-urban growth in Ethiopia, often leading to land competition and environmental degradation (D. Tilahun et al., 2022).

Agricultural land also expanded significantly, gaining over 3,320 hectares. This trend reflects ongoing conversion of natural landscapes, especially shrublands and forests, into cropland, driven by subsistence and possibly commercial farming. Such patterns mirror findings by (Wahelo et al., 2024), who observed widespread agricultural encroachment into ecologically sensitive areas across Ethiopia.

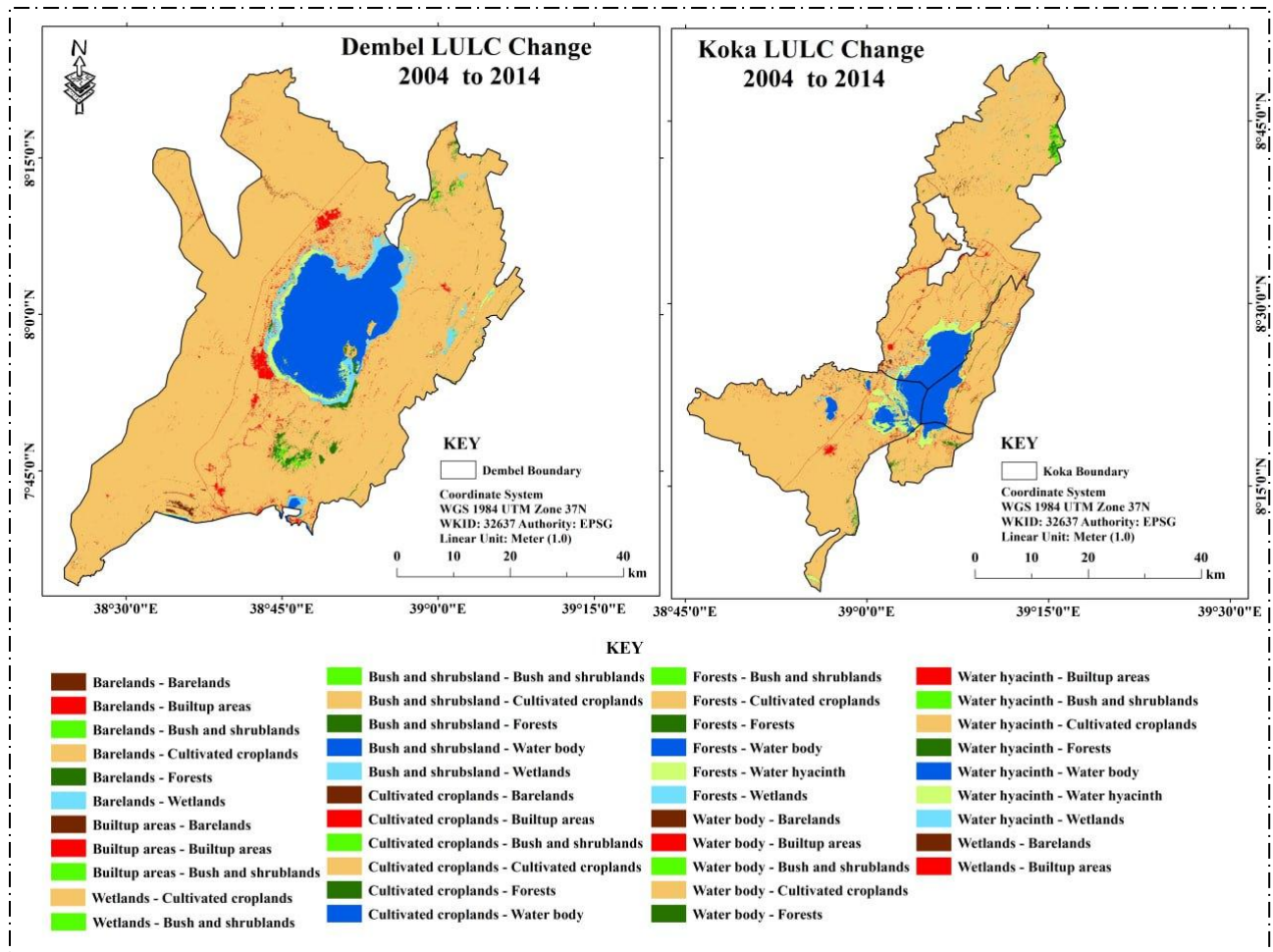
Shrubland experienced the most dramatic loss, declining by more than 8,560 hectares. This class, often acting as a buffer between ecosystems, is increasingly being converted into farmland and settlements. The reduction in ecological heterogeneity from this loss weakens the region’s resilience to environmental stress (Inkani et al., 2024; Etena et al., n.d.). Forests also declined by 1,043 hectares, reflecting continued pressure from farming and fuelwood harvesting. Despite being smaller in area, this loss is critical due to the forest's roles in carbon sequestration, biodiversity support, and soil stability (Gebrei, 2024).

Water bodies shrank by approximately 1,647 hectares, likely due to reduced rainfall, sedimentation, and abstraction patterns consistent with hydrological stresses reported in Ethiopia’s lowland basins (T. D. Mengistu et al., 2021). Conversely, wetlands expanded by 2,486 hectares, possibly due to seasonal flooding or regrowth in previously dried zones. Simultaneously, water hyacinth a known invasive species increased by about 1,240 hectares, signaling nutrient enrichment and stagnant water conditions. This ecological shift parallels findings in Lake Tana and Lake Ziway, where eutrophication promotes invasive aquatic vegetation (Y. Kassa et al., 2021).

In summary, Dembel's landscape between 2014 and 2024 shifted markedly from natural ecosystems toward built-up and agricultural uses. These trends emphasize the need for integrated land-use planning and environmental conservation strategies to balance development with ecological integrity.

**Table 9.** LULC Gain and Loss Summary Table (2014–2024)

<b>Land Cover Class</b>	<b>Gain (from other classes)</b>	<b>Loss (to other classes)</b>	<b>Net Change (Gain - Loss)</b>
<b>Bare-lands</b>	772.21	827.13	-54.92
<b>Built-up Areas</b>	7,243.82	2,989.84	+4,253.98
<b>Bush &amp; Shrub Lands</b>	945.91	9,506.64	-8,560.73
<b>Agricultural Lands</b>	291,497.98	288,177.43	+3,320.55
<b>Forest Areas</b>	3,588.01	4,630.62	-1,042.61
<b>Water Body</b>	37,234.11	38,880.70	-1,646.59
<b>Water Hyacinth</b>	4,198.52	2,954.10	+1,244.42
<b>Wetlands</b>	6,942.90	4,457.00	+2,485.90



**Figure 17.** Dembel catchment LULCC Change Matrix for 2014 to 2024

### 3.3.8.2 Koka Land cover change Loss-gain Matrix

Between 2014 and 2024, the Koka area underwent notable land use and land cover (LULC) changes shaped by both human activities and environmental factors (Table 10). Built-up areas increased by about 825 hectares, indicating moderate urban growth. This level of expansion, though less rapid than in some regions, aligns with urbanization trends observed across Ethiopia’s secondary towns (Mezgebo, 2020).

Agricultural land also expanded, gaining around 637 hectares. This modest growth suggests continued dependence on farming but may also reflect limits to available arable land, a pattern also reported in other saturated agricultural zones of Ethiopia (Teferi et al., 2025). However, the pressure from urban and agricultural expansion has come at the cost of natural land cover.

One of the most concerning changes is the decline in water bodies, which shrank by over 1,827 hectares during the decade. This reduction may be due to reduced inflows, sedimentation, or climate variability

similar to trends documented in other Ethiopian Rift Valley lakes (Ayenew and Legesse, 2007). Compounding this is the rapid spread of water hyacinth, which expanded by nearly 960 hectares. As a highly invasive aquatic species, its growth reflects deteriorating water quality and reduced water flow, issues previously observed in lakes such as Tana and Ziway (Wendimu et al., 2024a).

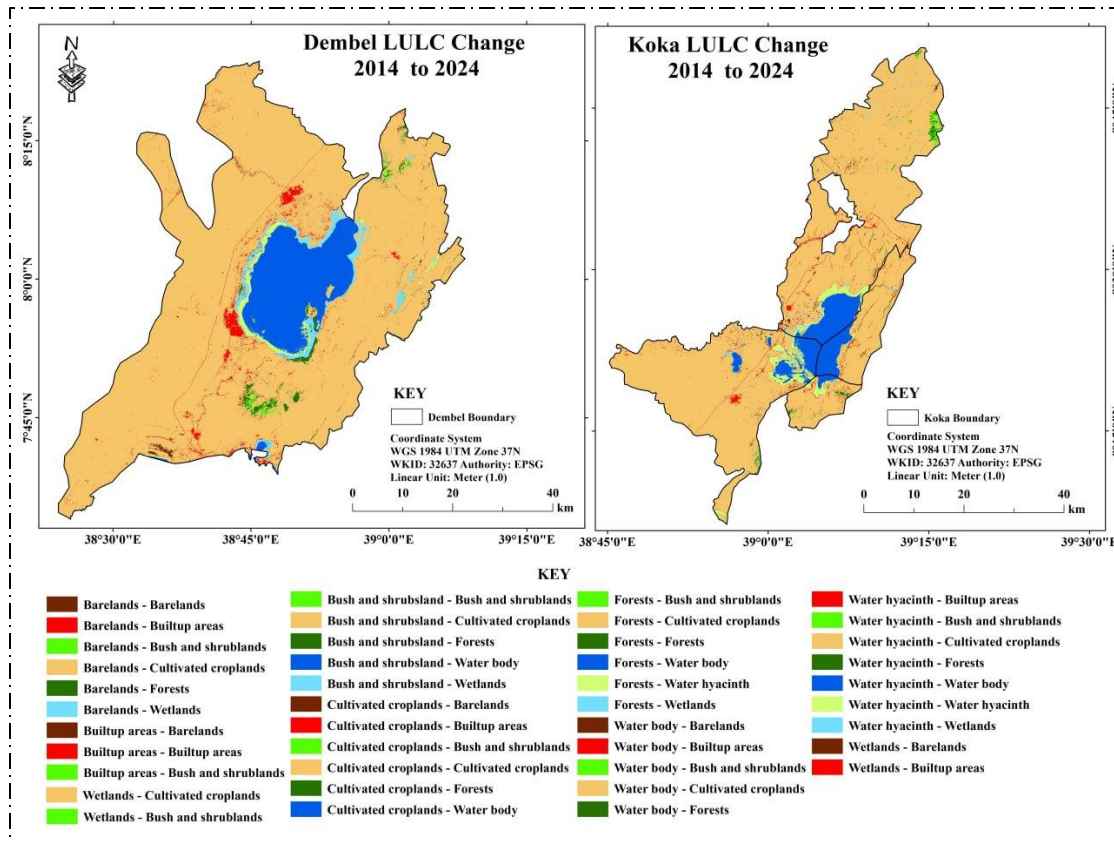
Natural vegetation continued to decline, with bush/shrub lands losing around 387 hectares and forests decreasing by approximately 306 hectares. These losses likely result from land conversion for farming, fuelwood collection, or settlement expansion, consistent with national-level patterns of gradual deforestation (Yesuph, 2020).

On a more positive note, wetlands in Koka increased by about 289 hectares. This slight gain may be linked to seasonal flooding or localized restoration, echoing findings from similar Ethiopian basins where natural wetland regeneration has been observed (Ntiaiei, 2023).

In summary, Koka’s landscape is shifting steadily toward more human-dominated land uses. Urban and agricultural expansion, while moderate, continues to exert pressure on natural ecosystems. The sharp decline in water bodies and the rise of invasive species like water hyacinth are critical warning signs of ecological imbalance. These changes call for integrated land and water management strategies to protect remaining natural resources and ensure environmental sustainability.

**Table 10.** LULC Gain and Loss Summary Table for Koka Study Area (2014–2024)

<b>Land Cover Class</b>	<b>Gain (from other classes)</b>	<b>Loss (to other classes)</b>	<b>Net Change (Gain - Loss)</b>
Bare-lands	589.17	779.07	<b>-189.90</b>
Built-up Areas	2,760.31	1,935.55	<b>+824.76</b>
Bush and Shrub Lands	590.65	977.24	<b>-386.59</b>
Agricultural Lands	119,362.05	118,724.60	<b>+637.45</b>
Forest Areas	1,271.56	1,577.56	<b>-306.00</b>
Water Body	11,120.49	12,948.06	<b>-1,827.57</b>
Water Hyacinth	4,199.21	3,240.18	<b>+959.03</b>
Wetlands	1,356.15	1,067.33	<b>+288.82</b>



**Figure 18.** Dembel catchment LULCC Change Matrix for 2014 to 2024

### 3.3.8.3 Comparative Analysis

Between 2014 and 2024, the Dembel and Koka basins of Ethiopia experienced notable land use and land cover (LULC) changes, driven by urban growth, agricultural expansion, and environmental shifts (Table 11). Dembel exhibited more rapid transformation, with built-up areas increasing by 4,254 hectares compared to Koka's 825 hectares. Agricultural land expanded by 3,321 hectares in Dembel, while Koka shows a smaller gain of 637 hectares, reflecting more intense land conversion in Dembel (Dessu et al., 2020).

This expansion came at the expense of the deforestation of natural vegetation. Dembel lost over 8,560 hectares of shrubland, the largest decline in either Basin, while Koka lost 387 hectares. Forest cover also decreased by: 1,043 hectares in Dembel and 306 hectares in Koka, consistent with ongoing deforestation for agriculture and energy (Chopra et al., 2022).

Water bodies decreased significantly in both regions: by 1,647 hectares in Dembel and 1,827 hectares in Koka, likely due to sedimentation, abstraction, and climate variability (Gebre et al., 2024). Concurrently,

water hyacinth a known invasive species spread rapidly, covering 1,244 hectares in Dembel and 959 hectares in Koka, indicating ecological impacts (Wassie et al., 2023).

In contrast, wetland areas expanded: Dembel gained 2,486 hectares and Koka 289 hectares, possibly due to seasonal flooding or targeted restoration (Teferi et al., 2015). These patterns reveal that while Dembel faced intense human-driven change, Koka's transformation was more aquatic-focused.

In summary, both basins show increasing pressure on natural ecosystems, but with differing dominant drivers. Dembel's changes are shaped largely by settlement and agriculture, while Koka's reflect aquatic ecosystem challenges. These findings underscore the urgency of basin-specific land management strategies to balance development with sustainability

**Table 11.** Comparative analysis of lulc changes between Dembel and Koka study areas (2014–2024)

LULC Class	Dembel: Major Trend	Koka: Major Trend
<b>Built-up Areas</b>	Significant increase (+4,254 ha)	Moderate increase (+825 ha)
<b>Agricultural Lands</b>	Large gain (+3,321 ha)	Moderate gain (+637 ha)
<b>Bush &amp; Shrub Lands</b>	Major loss (−8,561 ha)	Moderate loss (−387 ha)
<b>Forest Areas</b>	Modest loss (−1,043 ha)	Similar trend (−306 ha)
<b>Water Bodies</b>	Slight loss (−1,647 ha)	Severe loss (−1,828 ha)
<b>Water Hyacinth</b>	Notable gain (+1,244 ha)	Large gain (+959 ha)
<b>Wetlands</b>	Significant gain (+2,486 ha)	Moderate gain (+289 ha)

### 3.3.9 Accuracy assessment

Table 12 presents the accuracy assessment of the image classification of all LULC classification and LULC change. The accuracy assessment of land use and land cover (LULC) classifications for the Dembel and Koka Lakes Basin from 1994 to 2024 reveals consistently high classification performance, reinforcing the validity of the remote sensing methodology applied. Throughout the 30-year period, the overall accuracies ranged from 98.8% to 99.8%, with Kappa coefficients between 0.986 and 0.997, indicating near-perfect agreement (Pereira-Júnior et al., 2025).

In 1994, the classification achieved an overall accuracy of 99.6% and a Kappa statistic of 0.996. The lowest producer's accuracy was 97% for Bush and Shrub Land, while Water Bodies and Cropland reached 100%. Forests showed user's accuracy at 99%, suggesting minimal misclassification.

In 2004, a slight decline was observed with 98.8% overall accuracy and Kappa of 0.986. The lowest producer’s accuracy was 98% for Water Hyacinth and Cropland, while Wetlands recorded the lowest user’s accuracy at 95%, likely due to spectral overlap with adjacent land cover types, a common challenge noted in wetland mapping (Amani, 2018).

In 2014, the accuracy improved again to 99.6% (Kappa is 0.996). Built-up Areas had the lowest producer’s accuracy (98%), while Forests retained the lowest user’s accuracy (98%), consistent with other studies where forest and urban boundaries are prone to misclassification in heterogeneous landscapes (Tran, 2013).

The 2024 classification reached peak performance with 99.8% accuracy and Kappa of 0.997. All classes achieved producers’ and users’ accuracies above 99%, indicating excellent separability and classification robustness. This performance surpasses the accuracy benchmarks recommended by Basaraner and Cetinkaya, (2017), who suggest that accuracies above 85% are generally acceptable for LULC mapping.

These high-accuracy results are in line with other regional studies. For example, ADEM, (2023) reported high classification accuracy using Landsat data in Ethiopia’s highlands, affirming the reliability of supervised classification with ground validation. Similarly, (S. B. Kassa et al., 2025) achieved comparable performance in the Central Rift Valley, supporting the repeatability of such results across varied Ethiopian ecologies.

**Table 12.** Summary of Accuracy Assessment for Dembel and Koka Lakes Basin (1994–2024)

Year	Overall Accuracy	Kappa Statistic	Lowest Producer’s Accuracy	Lowest User’s Accuracy
<b>1994</b>	0.996	0.996	Bush and Shrub Land (0.97)	Forests (0.99)
<b>2004</b>	0.988	0.986	Water Hyacinth (0.98)	Wetland (0.95)
<b>2014</b>	0.996	0.996	Built-up Area (0.98)	Forests (0.98)
<b>2024</b>	0.998	0.997	Built-up Area (0.99)	Forests (0.99)

### 3.4 Conclusion

The comprehensive analysis of land-use and land-cover (LULC) change in the Dembel and Koka catchments reveals significant ecological and environmental implications over the upcoming decades. Both catchments are facing challenges primarily driven by the proliferation of water hyacinth, agricultural intensification and increasing urbanization, which threaten the integrity of aquatic ecosystems and native vegetation.

In Dembel Lake, the rise of water hyacinth indicates an alarming shift in aquatic biodiversity, potentially outcompeting native flora and impacting water quality. Land use land cover change analysis suggest a continued expansion of agricultural lands, raising concerns about sustainability and land degradation. The interplay between urban development and ecological preservation underscores the urgent need for effective management strategies.

Conversely, the Koka catchment shows a stark increase in built-up areas. This rapid urbanization, coupled with significant agricultural expansion, poses a risk to wetlands and forest areas, which are declining in trend. The ongoing encroachment of water hyacinth further complicates these dynamics, reinforcing the necessity for integrated land-use planning.

The slight increase in lake coverage between 1994 and 2004 could be attributed to temporary factors such as increased rainfall, such as the El Niño rain in the 1990s. However, from 2004 onwards, the lake's coverage shows a steady decline, likely driven by increased human activities around the lake that degrade its natural inflow and outflow balance and ongoing water diversion for agriculture. Moreover, hyacinth's evapotranspiration rate (3× open water) directly reduces lake volume. This downward trend raises concerns about the lake's long-term health, affecting local ecosystems and communities relying on its resources

Overall, these findings highlight the critical importance of proactive measures to manage invasive species, promote sustainable agricultural practices, and protect natural habitats. The challenges identified necessitate collaborative efforts among policymakers, researchers, and local communities to ensure the ecological health and sustainability of both catchments for future generations.

The study urges future research on addressing the root causes of water hyacinth proliferation and implementing sustainable management practices. This would enhance efforts exerted to mitigate the adverse impacts of this invasive species and protect vital ecosystems and communities of Ethiopia's central Rift Valley.

## **Chapter 4: Environmental Impacts of Water Hyacinth Proliferation in the Rift Valley Lakes of Ethiopia: The Case of Koka and Dembel**

### **Abstract**

*Freshwater ecosystems are indispensable to biodiversity and human livelihoods, yet they face mounting threats from nutrient pollution, primarily nitrogen and phosphorus, which lead to eutrophication. This study examines the nutrient pollution in Lakes Koka and Dembel in the Oromia region, revealing historical and current trends in nutrient loads that threaten these vital water bodies. Historical data underscore a significant rise in total phosphorus concentrations, particularly in Lake Koka, attributed to effluent discharge and agricultural runoff. Lake Dembel showed TN (0.47–7.86 mg/L) and TP (0.07–1.64 mg/L), with TP exceeding eutrophication thresholds. Lake Koka had higher pollution, with TN (0.83–8.96 mg/L) and TP (0.14–3.8 mg/L), particularly near agricultural inflows. The assessments indicate alarmingly high nutrient levels, with Lake Koka exhibiting higher pollution loads than Lake Dembel. The nutrient concentrations surpass eutrophication thresholds in both lakes, necessitating urgent management strategies such as enhanced monitoring, sustainable agricultural practices, improved wastewater treatment, and community engagement. The proliferation of water hyacinth (*Eichhornia crassipes*) further complicates the ecological balance, impacting land use and land cover (LULC) patterns. The spread of this invasive species has intensified in both lakes, altering local hydrology and rendering areas unsuitable for fishing and navigation, thereby disrupting socio-economic activities. Our study documents significant land cover transitions influenced by water hyacinth, highlighting its ecological and economic ramifications. Integrated management strategies, community involvement, and nutrient management are recommended to curb its spread and restore ecological integrity. In the Central Rift Valley, water hyacinth threatens landscape beauty and tourism potential. Its impact on navigation and endemic species poses a substantial risk to the region's economic and ecological well-being. Recommendations include integrated control measures, biodiversity conservation, and policy incentives to foster sustainable tourism and resource use. The fishery sector, pivotal to local economies around Lake Dembel, suffers from the adverse effects of water hyacinth. A marked decline in fish production and increased operational costs underscores the economic losses experienced by fishing communities. To mitigate these impacts, a combination of physical removal, biological control, and community engagement in sustainable practices is essential. Strengthening research and policy frameworks can enhance resilience and secure livelihoods dependent on this resource. This research underscores the urgent need for coordinated management efforts to address nutrient pollution and invasive species, thereby preserving the ecological and socio-economic value of Lakes Koka and Dembel.*

**Keywords:** water hyacinth, water pollution, landscape, ecosystem, land use land cover; fish productio

## 4.1 Introduction

Water hyacinth, *Eichhornia crassipes*, is one of the most invasive aquatic plants globally (Abba and Sankarannair, 2024). Its proliferation is primarily driven by nutrient-rich waters, high temperatures, and favorable hydrological conditions (Karouach et al., 2022a). For instance, the coverage of water hyacinth in Lake Tana increased by 96% from 2011 to 2019, although it shows a temporary decline in specific years due to environmental changes (Abebe et al., 2023). The plant's ability to reproduce rapidly, doubling its population in as little as two weeks, exacerbates its spread (Levin, 2000). The growth rate of water hyacinth is influenced by various factors, including nutrient availability and water temperature. In some regions, such as Florida, populations can double in two weeks, making it one of the fastest-growing plants (Geary, 1983). Future trends indicate continued proliferation, particularly in regions with increasing urbanization and nutrient runoff (Patel, 2020.) Water hyacinth significantly affects landscapes, water quality, and ecosystems. It forms dense mats that block sunlight, reducing oxygen levels in the water and harming aquatic life. These mats also impede water flow, leading to increased sedimentation and water quality deterioration (Harun et al., 2021). Economically, the plant disrupts fishing activities, navigation, and agriculture, imposing costs on local economies (Abba and Sankarannair, 2024). The current proliferation rate is driven by human activities that increase nutrient levels in water bodies, such as agricultural runoff and sewage discharge (Karouach et al., 2022b). Climate change, with its associated temperature increases, also plays a significant role in promoting water hyacinth growth. Water hyacinth poses challenges to several SDGs, particularly those related to clean water and life below water. However, it also offers potential benefits, such as bioenergy production and wastewater treatment, aligning with goals for sustainable management of water resources (Nyandoro, 2019; Güereña et al., 2015). Studying the impacts of water hyacinth proliferation is crucial for developing effective management strategies to mitigate its adverse effects on biodiversity, water quality, and local economies. It also provides insights into harnessing its potential benefits, such as its use in phytoremediation and bioenergy production (Karouach et al., 2022a).

Water hyacinth is notorious for its impact on water quality. This invasive aquatic plant can completely cover lakes and wetlands, leading to a reduction in oxygen levels, which is critical for aquatic life. The dense mats formed by water hyacinth can diminish light penetration, affecting the photosynthesis of submerged plants, and result in decreased dissolved oxygen levels, which is detrimental to fish populations and other aquatic organisms (Howard and Harley, 1997). These mats also serve as a breeding ground for mosquitoes and other pests, further affecting water quality through increased disease vectors. Additionally, the decomposition of water hyacinth when they die off can lead to significant nutrient loads in the water, exacerbating eutrophication and leading to algal blooms (Dersse et al., 2019). Globally, water hyacinth is recognized as a major ecological threat. It alters water quality by affecting parameters

such as temperature and turbidity, and it also competes with native species, further destabilizing ecosystems (Mironga et al., 2012). In Africa, the situation is particularly acute. The water hyacinth has spread rapidly across freshwater bodies, impacting not only biodiversity but also local economies that rely on these waters. For instance, in Lake Victoria, the plant has significantly hampered fishing activities and water transport due to its dense growth (Opande et al., 2004). Case studies from African countries highlight the severe impacts of water hyacinth on water quality. In Nigeria and South Africa, the plant's proliferation has been linked to increased nutrient loading and subsequent eutrophication in water bodies. These countries have observed deteriorations in water quality, making the water less suitable for consumption and other uses (Onyari et al., 2024). In Uganda, particularly around Lake Victoria, water hyacinth has been associated with increased incidences of diseases like malaria and bilharzia due to the conducive environment the mats provide for mosquitoes (De Groote et al., 2003). The presence of water hyacinth also impacts water quantity. The thick mats can lead to increased water loss through evapotranspiration. The plant's rapid expansion can block sunlight, reducing the productivity of the aquatic ecosystem and leading to the loss of native species (Addis and Desta, 2024). Furthermore, studies in Lake Tana have shown significant reductions in water volume due to the presence of water hyacinth, affecting the region's water availability for irrigation and other uses (Nerae et al., 2024). Hence, the pervasive nature of water hyacinth poses a substantial threat to water quality and quantity across the globe, with particularly severe impacts in Africa. Its management requires coordinated efforts to mitigate its spread and restore affected water bodies.

Water hyacinth, a pervasive aquatic weed, significantly alters land use and land cover by encroaching on water bodies and adjacent lands. Its invasion leads to a reduction in agricultural and grazing lands as it proliferates over water surfaces and floods surrounding areas. This can cause a loss of productive land, affecting agriculture and livestock activities due to the physical space taken up by this plant and its impact on water quality (Damtie et al., 2021). The dense mats formed by water hyacinth impede water flow, which can lead to changes in the landscape, such as increased sedimentation and the potential for flooding in nearby areas. This has a profound impact on the surrounding land cover, leading to possible changes in the types of vegetation that can grow and thrive in these altered conditions (Abba and Sankarannair, 2024). Globally, water hyacinth affects land use by reducing the accessibility and usability of waterways for transportation and recreation, which can have economic repercussions for communities that rely on these activities. In Africa, the impact is particularly severe, where the plant covers significant portions of water bodies, affecting local economies dependent on fishing and agriculture. For example, in Nigeria and South Africa, the proliferation of water hyacinth has led to loss of agricultural productivity and increased costs in managing the invasive species (Onyari et al., 2024). In Africa, case studies highlight the challenges posed by water hyacinth. In Lake Victoria, which spans Uganda, Tanzania, and Kenya, the

plant has significantly altered the landscape, affecting fish populations and thus impacting fishing communities that rely on these resources for their livelihood (Yara, 2019). In Ethiopia, the spread of water hyacinth has led to a notable increase in land covered by the weed, affecting rice cultivation by reducing the area available for farming and increasing the costs associated with managing this invasive species (Van Wyk and Van Wilgen, 2002). The proliferation of water hyacinth also directly impacts fishing activities by blocking access to fishing sites, damaging fishing gear, and altering fish habitats. This not only affects the economic viability of fishing communities but also has a broader impact on land use as communities may need to shift their activities away from fishing to other forms of livelihood (Addis and Desta, 2024; Wendimu et al., 2024; Ongore et al., 2018). Overall, the presence of water hyacinth represents a significant environmental challenge, necessitating integrated management strategies to mitigate its impact on land use, land cover, and landscapes across affected regions.

Water hyacinth significantly impacts fishing by reducing access to fishing zones, entangling nets and propellers, and blocking fish landing sites. This leads to reduced fish catches and increased difficulty in navigating water bodies for fishing activities. The dense mats of water hyacinth lower dissolved oxygen levels, causing fish die-offs and disrupting local fish populations (Rahel and Olden, 2008). Globally, water hyacinth affects fisheries by hindering fishing efforts, leading to economic losses in communities reliant on fishing. In Africa, the impact is pronounced with instances such as in Lake Victoria, where the weed has severely hindered fishing activities by covering large areas and reducing fish stock accessibility (Kateregga and Sterner, 2009). In Lake Naivasha, Kenya, water hyacinth has led to the destruction of fishing gear and reduced fish populations due to oxygen depletion. Similarly, in Lake Victoria, fishing communities face reduced catches and increased operational costs due to the weed's interference with fishing activities (Addis and Desta, 2024). The impact of water hyacinth varies spatially, with different regions experiencing varied levels of infestation. In some areas, such as Lake Victoria, water hyacinth has led to significant changes in fisheries management and local economies. The spatial distribution of the weed affects fish diversity and abundance, with some areas experiencing more severe impacts than others (Mekuria et al., 2021). Water hyacinth also impacts land use and water pollution. It causes shifts in land cover by proliferating in water bodies, which affects local ecosystems and biodiversity. The weed contributes to water pollution by trapping debris and reducing water quality, further affecting aquatic life and human activities (Damtie et al., 2022a). Overall, the presence of water hyacinth poses significant challenges to fishing industries and local communities, especially in regions heavily reliant on fishing for livelihood. Efforts to manage and mitigate the impacts of this invasive species are crucial for sustaining fisheries and protecting aquatic ecosystems.

Water hyacinth has significantly affected water quality in Ethiopian lakes, such as Lake Dembel and Lake Tana. It degrades water's physicochemical properties, leading to reduced oxygen levels and increased nutrient loads, which can harm aquatic life (Gezie et al., 2018). The invasion of water hyacinth in Ethiopian water bodies has led to decreased water availability. The dense growth of the plant obstructs water flow and reduces the surface water available for consumption and irrigation (Churko, Nhamo, et al., 2023). Water hyacinth affects land use by spreading into agricultural lands and pastures, leading to loss of usable land and altering landscapes. It also impacts the livelihoods of communities relying on agriculture and fishing, as it hinders access to water bodies and degrades habitat quality (Asmare, 2017). The infestation of water hyacinth in Lake Tana has negatively impacted fishing activities by reducing fish catches and hindering access to fishing areas. The weed entangles fishing nets and boats, leading to increased operational costs for fishermen. Despite the evident impacts, there are significant research gaps in understanding the full ecological and economic implications of water hyacinth in Ethiopia. More studies are needed to explore effective management strategies, the socio-economic effects on local communities, and long-term ecological changes. Current efforts often focus on immediate management rather than comprehensive ecosystem-based approaches (Dersseh, Kibret, et al., 2019;. Damtie, 2022) Addressing these gaps is crucial for developing sustainable solutions to manage the water hyacinth invasion and mitigate its adverse effects on the environment and local economies in Ethiopia.

The study of water hyacinth impacts in Ethiopia is highly relevant due to the significant threats it poses to water bodies and local economies. Water hyacinth degrades water quality, reduces water availability, and disrupts fishing activities, which are crucial for the livelihoods of many Ethiopians. Understanding these impacts is essential for developing effective management strategies to protect Ethiopia's aquatic ecosystems and enhance sustainable resource use (Mengist and Moges, 2019). Case studies of water hyacinth provide valuable insights into ecological dynamics, invasive species management, and environmental remediation. They offer empirical data that can inform broader ecological theories and contribute to the development of innovative solutions for managing aquatic ecosystems affected by invasive species (Yan et al., 2017). Studying water hyacinth proliferation enriches the scientific literature by advancing our understanding of invasive species dynamics and their ecological impacts. It highlights the need for interdisciplinary approaches to tackle complex environmental challenges and builds a foundation for future research on similar invasive species (Harun et al., 2021). Research on water hyacinth aligns with several Sustainable Development Goals (SDGs), including ensuring clean water and sanitation (SDG 6) and promoting sustainable use of aquatic ecosystems (SDG 14). By addressing the environmental and socio-economic impacts of water hyacinth, studies contribute to global efforts to achieve sustainable development and improve the resilience of communities affected by invasive species (Seboka et al., n.d.).To make water hyacinth studies globally relevant, researchers can focus on

developing scalable management practices, leveraging remote sensing technologies for monitoring, and promoting international collaboration. Sharing knowledge and solutions across borders can enhance global understanding of invasive species management and foster collective action against the spread of water hyacinth (Datta et al., 2021). This comprehensive approach not only addresses local challenges but also contributes to global environmental health and sustainability.

The primary objective of this study is to comprehensively assess the impacts of water hyacinth on various environmental parameters, including water quality, water quantity and availability, land use and cover, landscape alterations, and fishing activities. The study aims to provide a holistic understanding of how water hyacinth affects these critical environmental factors and to identify effective management strategies to mitigate its negative impacts. By identifying the specific ways in which water hyacinth impacts various environmental factors, the study will provide empirical data for the policy makers and planners working on developing targeted management strategies aimed at controlling its spread and mitigating its adverse effects. The outcomes will contribute to the formulation of policies that address the ecological and socio-economic challenges posed by water hyacinth, promoting sustainable environmental practices. Overall, the study will significantly contribute to the broader understanding of invasive species management and the preservation of environmental health and sustainability.

## **4.2 Methodology**

### **4.2.1 Data Collection**

#### **Sampling sites**

A comprehensive evaluation was conducted across twenty-four water sampling sites, with nine sites located in Lake Koka and fifteen in Lake Dembel. The selection of these sites was based on preliminary surveys and historical data regarding pollution levels. Sampling was performed during the dry season to minimize variability due to precipitation. Each site was sampled once, with samples collected from approximately 0.5 meters below the water surface to ensure consistency. Composite samples were collected to provide a well-rounded perspective on the nutrient dynamics in these lakes

#### **Sample Collection and Preparation**

Water samples were collected using pre-cleaned polyethylene bottles. Bottles were rinsed with lake water prior to sample collection to avoid contamination. Samples were immediately placed in coolers with ice packs and transported to the laboratory, where they were stored at 4°C until analysis. All samples were analyzed within 24 hours of collection to ensure data integrity and reliability.

## **4.2.2 Laboratory Analysis**

### **pH**

The pH of the water samples was measured using a calibrated digital pH meter. Calibration was performed with standard buffer solutions of pH 4.0, 7.0, and 10.0 before each set of measurements. The pH values were interpreted with a normal range of 6.5 to 8.5 for freshwater ecosystems (Wetzel and Limnology, 2001).

### **Dissolved Oxygen (DO)**

Dissolved Oxygen levels were determined using the Winkler method, which involves the addition of manganese sulfate and alkaline iodide to the water sample, followed by titration with sodium thiosulfate. The standard range for DO in healthy aquatic environments is between 5.0 and 14.0 mg/L (Chapman, 2021).

### **Temperature**

Water temperature was recorded in situ using a mercury thermometer. The temperature is crucial as it affects the solubility of oxygen and the metabolic rates of aquatic organisms. Typical temperatures for temperate lakes range between 4°C and 25°C (Wetzel and Limnology, 2001).

### **Total Nitrogen (TN) and Nitrate-Nitrogen (NO<sub>3</sub>-N)**

Total Nitrogen was measured using the persulfate digestion method followed by nitrate determination using a spectrophotometer. For NO<sub>3</sub>-N, samples were filtered and analyzed using the cadmium reduction method. Acceptable levels for TN in freshwater are usually below 1.0 mg/L, while NO<sub>3</sub>-N should not exceed 10.0 mg/L (U.S. EPA, 2002).

### **Ammonia-Nitrogen (NH<sub>3</sub>-N)**

Ammonia concentrations were determined using the phenate method. The samples were filtered and reacted with phenol and hypochlorite, forming indophenol blue, which was then measured spectrophotometrically. Safe levels for NH<sub>3</sub>-N are typically below 0.1 mg/L (U.S. EPA, 2002).

### **Total Phosphorus (TP) and Soluble Reactive Phosphate (SRP-PO<sub>4</sub>).**

TP was analyzed using the ascorbic acid method following acid digestion of the sample. SRP-PO<sub>4</sub> was measured directly after filtration using the same method. TP levels should be below 0.1 mg/L to prevent eutrophication, while SRP-PO<sub>4</sub> should not exceed 0.03 mg/L (Wetzel and Limnology, 2001).

## **Sulphate and Sulfide**

Sulphate levels were assessed using ion chromatography, and sulfide concentrations were determined using the methylene blue method. Healthy freshwater systems typically exhibit sulphate levels below 50 mg/L and sulfide concentrations under 0.05 mg/L (Chapman, 2021).

## **Salinity**

Salinity was measured using a handheld refractometer. Freshwater systems generally have salinity levels below 0.5 ppt (parts per thousand) (Wetzel and Limnology, 2001).

### **4.2.3 Data Analysis and Interpretation**

The data collected from the 24 sampling sites underwent a comprehensive analysis to assess the water quality and identify potential pollution sources. The statistical analysis was performed using SPSS version 25, a robust software package that provides a wide range of statistical tools essential for environmental data analysis.

Firstly, descriptive statistics were calculated for each parameter to establish baseline values and understand the distribution of data across the sites. This included measures of central tendency such as mean and median, as well as measures of variability like standard deviation and range. These statistics provided initial insights into the general water quality conditions and helped identify any outliers or anomalies in the data set.

Comparative analysis between polluted and undisturbed sites was conducted using Analysis of Variance (ANOVA). This statistical method was chosen because it allows for the comparison of means across multiple groups and can effectively determine if there are statistically significant differences between the groups. In this study, ANOVA was used to assess whether the levels of each parameter differed significantly between the polluted and undisturbed sites. A p-value of less than 0.05 was considered indicative of a significant difference.

In addition to ANOVA, correlation analysis was performed to explore relationships between different water quality parameters. Pearson correlation coefficients were calculated to quantify the strength and direction of linear relationships between pairs of parameters. For instance, understanding the correlation between nutrient levels (such as TN and TP) and biological indicators (like DO) can provide insights into potential nutrient pollution effects and ecosystem health.

The results from these analyses were interpreted in the context of ecological health standards and historical data for the region. By comparing the measured values to established guidelines and previous

studies, we could assess the current state of the lakes and identify any deviations from expected conditions. This contextual interpretation is crucial for understanding the potential impacts of observed pollution levels on aquatic life and ecosystem processes.

## **4.3 Results and Discussion**

### **4.3.1 Water Pollution**

Freshwater ecosystems are critical to both biodiversity and human livelihoods. However, they are increasingly threatened by nutrient pollution, leading to eutrophication a process characterized by excessive nutrients, primarily nitrogen and phosphorus, which promotes excessive plant growth and disrupts aquatic ecosystems (Kiyemba, 2021; Chapman, 2021). This study focuses on assessing the nutrient loads in Koka and Dembel lakes, two significant water bodies in the Oromia region, to understand the extent and sources of pollution impacting these lakes.

#### **Historical Trends of Nutrient Pollution Load**

The escalating issue of nutrient over-enrichment in Lakes Koka and Dembel is part of a broader environmental crisis affecting the sub-basin. Historical data indicate a sharp rise in total phosphorus (TP) concentrations, particularly in Lake Koka (G. Tilahun et al., n.d.) (Gebreegziabher et al., 2023). This increase is largely attributed to continuous nutrient inflow from the Modjo and Awash Rivers, which carry domestic and industrial effluents (Mamo et al., 2020). Additionally, phosphorus accumulation from chemical fertilizers used in agricultural activities around Lake Koka contributes to this trend. In contrast, Lake Dembel, with a larger water volume of 43,700 hectares compared to Koka Lake's 16,230 hectares, benefits from a dilution effect, potentially maintaining lower nutrient concentrations (Villamagmka and Murphy, 2010).

#### **Current Nutrient Pollution Load**

Recent assessments reveal alarming levels of nutrient pollution in both lakes. In Lake Dembel, total nitrogen (TN) and total phosphorus (TP) concentrations ranged from 0.47 to 7.86 mg/L and 0.07 to 1.64 mg/L, respectively, with mean values of 3.35 mg/L and 0.63 mg/L. The concentrations of nitrate-nitrogen and phosphate were 2.26 mg/L and 0.19 mg/L, respectively, while sulfate averaged 16.38 mg/L. The susceptibility of Lake Dembel to eutrophication is evidenced by TP concentrations exceeding 0.1 mg/L in most sampling sites. Historical studies (Dagne, 2017) reported lower TN and TP values, highlighting a significant increase in current levels (Table 13).

In Lake Koka, TN concentrations ranged from 0.83 to 8.96 mg/L, while TP ranged from 0.14 to 3.8 mg/L. The nutrient loads from the Awash and Modjo Rivers were notably high, with TN values of 5.15 and 8.96

mg/L and TP values of 3.5 and 3.8 mg/L, respectively. The mean concentrations of TN and TP in Lake Koka were 4.55 mg/L and 1.79 mg/L. Nitrate and phosphate concentrations averaged 2.79 mg/L and 0.67 mg/L, while sulfate ranged from 37.67 to 106.67 mg/L, averaging 72.31 mg/L. Lake Koka exhibited higher pollution loads compared to Lake Dembel, particularly in areas with intense agricultural activities like Lafesa.

Table 13. Mean Pollution Loads in Koka and Dembel Lakes

Parameters	Lake Dembel			Lake Koka		
	Mean Value	Min	Max	Mean Value	Min	Max
pH	8.52	7.8	9.24	8.48	8.48	8.96
DO	8.5	4.48	15.9	8.66	8.66	10.72
Temp	23.31	18.2	28.8	24.64	24.64	27.3
TN	3.35	0.47	7.86	4.55	0.83	8.96
NO <sub>3</sub> -N	2.26	0.24	5.67	2.79	0.14	4.87
NH <sub>3</sub> -N	0.86	0.18	1.85	2.26	0.3	8
TP	0.63	0.07	1.64	1.79	0.14	3.8
SRP-PO <sub>4</sub> <sup>-3</sup>	0.19	0.06	0.35	0.69	0.14	2.45
Sulphate	16.38	0.27	50	72.31	37.67	106.67
Sulfide	0.03	0.01	0.04	0.03	0.02	0.03
Salinity	250.3	212.57	330.1	283.28	1.26	712.5

The nutrient concentrations in Lakes Koka and Dembel are significantly above critical thresholds for eutrophication, posing severe risks to aquatic ecosystems and water quality. To mitigate these impacts, it is imperative to implement targeted management strategies.

Water hyacinth affects water quality by reducing dissolved oxygen levels due to decomposition, blocking sunlight penetration, and altering nutrient cycles. This leads to eutrophication, loss of aquatic biodiversity, and increased toxicity from trapped pollutants

- **Enhanced Monitoring and Regulation:** Establish stringent monitoring protocols to ensure nutrient levels in inflowing streams do not exceed recommended thresholds of 0.05 mg/L for streams and 0.025 mg/L within the lakes (Wetzel and Limnology, 2001; Assefa et al., 2020)
- **Agricultural Best Practices:** Promote sustainable agricultural practices to reduce phosphorus runoff from fertilizers. This can involve the use of buffer strips and controlled fertilizer application techniques (Carpenter et al., 1998).

- **Pollution Control Measures:** Improve wastewater treatment facilities to reduce effluent discharge from industrial and domestic sources into the lakes (Correll, 1998).
- **Community Engagement and Education:** Engage local communities in conservation efforts through education and awareness programs to foster sustainable interactions with these vital water resources (Pretty, 2003).

By adopting these measures, the health and sustainability of Lakes Koka and Dembel can be preserved, benefiting both the environment and the local communities that depend on these freshwater resources.

### **4.3.2 Impacts of Water Hyacinth on Land Use Land Cover and Landscape**

The invasive aquatic plant, water hyacinth (*Eichhornia crassipes*), poses significant challenges to ecosystems and socio-economic activities worldwide. Its proliferation creates a feedback loop that alters land use and land cover (LULC) patterns, further complicating management efforts. Dense mats of water hyacinth can modify local hydrology, making areas unsuitable for essential activities like fishing and navigation, thus impacting land use patterns (Garedew et al., 2009). This cyclical interaction where each factor influences and exacerbates the other is particularly evident in the lakes Koka and Dembel.

#### **Proliferation Trends in Lakes Koka and Dembel**

In Lake Koka, water hyacinth coverage has expanded dramatically from 1,378 hectares in 1994 to 4,199 hectares in 2024, representing a 104% increase. Lake Dembel presented no water hyacinth coverage in the years 1994 and 2004. However, by 2014, coverage reached 1,214 hectares, and by 2024, it had surged to 4,210 hectares, indicating a gain of 3,996 hectares (Table 6). Similar trends have been documented by Gichuki et al., (2012), where nutrient enrichment and aquatic ecosystem changes facilitate the spread of such invasive species (Dubey and Dutta, 2020).

#### **Impacts on Land Use Patterns**

The areas affected by water hyacinth become less suitable for fishing, navigation, and recreation, leading to alterations in surrounding land use patterns, including further development or abandonment of certain areas (Tewabe, 2015). The ecological degradation caused by water hyacinth can reduce essential ecosystem services such as water purification, habitat provision, and flood regulation, necessitating further land cover changes, like increased deforestation for new agricultural land, perpetuating the cycle (Villamagna and Murphy, 2010).

## Land Use/Land Cover Transitions

To illustrate the impacts of water hyacinth on LULC patterns, Figures 14 and 15 (Annex1 Tables 7 and 8) present the LULC transitions between 2014 and 2024 for the Koka and Dembel catchments, respectively. Diagonal values reflect land cover transitions to itself during the same period, while vertical columns indicate land use transitions between the 1994 to 2004 period.

In the Lake Koka catchment, water hyacinth showed a significant net gain in land cover between 2014 and 2024 (Annex1 Table 8). During this decade, water hyacinth increased by 1,241.25 hectares from other land uses while losing 282.22 hectares to other land uses. The land uses contributing to the increase in water hyacinth land cover were water bodies, forests, and bare lands, with contributions of 1,150.51 hectares, 90.73 hectares, and 0.01 hectares, respectively. Thus, the net gain of water hyacinth in this period was approximately 959.03 hectares.

Similarly, in the Lake Dembel catchment, water hyacinth exhibited a significant increase in land cover of 1,244.42 hectares. Contributors to this land cover gain included water bodies, bush and shrub lands, agricultural lands, forests, and bare lands, with contributions of 1,149.57 hectares, 137.81 hectares, 122.11 hectares, 55.67 hectares, and 18.77 hectares, respectively. These land uses collectively contributed 1,483.93 hectares.

The proliferation of water hyacinth in Lakes Koka and Dembel illustrates a complex interplay between ecological and socio-economic factors, fundamentally altering land use and land cover patterns. This situation not only disrupts local livelihoods but also degrades essential ecosystem services. To address these challenges, the following recommendations are proposed:

- **Integrated Management Strategies:** Implement a comprehensive management approach that combines mechanical, biological, and chemical control methods to effectively manage water hyacinth proliferation (Charudattan, 1986).
- **Nutrient Management:** Reduce nutrient inputs into lakes through improved agricultural practices and enhanced wastewater treatment facilities to curb the growth of water hyacinth (Carpenter et al., 1998).
- **Community Engagement:** Foster community involvement in managing water hyacinth through awareness programs and participatory management initiatives to ensure sustainable outcomes (Pretty, 2003).

- **Monitoring and Research:** Establish long-term monitoring and research programs to understand the dynamics of water hyacinth proliferation and its impact on LULC changes, facilitating adaptive management strategies (Nampindo, 2014; Pande et al., 2024).

By implementing these recommendations, it is possible to mitigate the adverse effects of water hyacinth, restoring and preserving the ecological integrity of Lakes Koka and Dembel while supporting the socio-economic well-being of the surrounding communities.

### **4.3.3 Impacts of Water Hyacinth on Landscape Beauty and Tourism in the Central Rift Valley**

The Central Rift Valley, encompassing iconic features such as Lakes Dembel and Koka, is historically renowned for its scenic beauty and tourism potential. This region plays a vital role in both local and national economies through eco-tourism, as supported by the then Federal Environment, Forest, and Climate Change Commission of the Federal Democratic Republic of Ethiopia (FDRE) and the current EPA (Environmental Protection Authority). The commission's total economic valuation exercise highlights the extraordinary eco-tourism potential of the area, estimating the economic contribution of Lake Dembel alone to exceed 128 million ETB annually (FEFCCC, 2018). Despite this potential, several factors, including invasive alien weeds like water hyacinth, waste disposal, unwise resource use, and urbanization expansion, threaten to deplete this potential

Key informants and focus group participants emphasize the historical significance of Lakes Dembel and Koka as central attractions in the Central Rift Valley. However, the infestation of water hyacinth poses a significant threat to tourism, landscape beauty, and recreational activities. Over two-thirds of surveyed households identified water hyacinth as a serious threat to these sectors. The weed's dense mats obstruct boat navigation, limiting tourist access to various locations within the wetlands. This restriction is particularly concerning for communities reliant on tourism and recreational activities, as their livelihoods and cultural heritage are increasingly vulnerable.

An in-depth discussion with key informants revealed that the transportation of tourists and goods on Lake Dembel is frequently impeded by water hyacinth. Participants conducted a simple trend analysis to illustrate the declining tourism activity in the area and its impact on local livelihoods. The potential for long-term water transport disruption is high if the infestation is not addressed through integrated wetland management strategies. The economic implications are significant; interruption of touring services and navigation due to water hyacinth could cost millions of ETB in lost revenue from tourism and goods transportation, leading to job losses for many households.

Beyond its economic impact, water hyacinth also threatens biodiversity in the Central Rift Valley. Key informants expressed concern about the weed's effect on endemic bird species, which are a primary attraction for foreign tourists, particularly bird watchers. The loss of these species would diminish the area's biodiversity and reduce its appeal as a tourism destination, further exacerbating economic losses. The proliferation of water hyacinth in the Central Rift Valley presents a substantial threat to the region's landscape beauty, tourism potential, and biodiversity. To mitigate these impacts, a multifaceted approach is essential.

- **Integrated Management and Control Measures:** Employ a combination of mechanical, biological, and chemical control methods to manage water hyacinth effectively. This approach should be part of a broader wetland management strategy that includes habitat restoration and conservation efforts (Kiyemba et al., 2023; Addis and Desta, 2024)
- **Community Involvement and Awareness:** Engage local communities in managing water hyacinth through education and participatory initiatives. Empowering communities to take part in conservation efforts can foster sustainable practices and enhance resilience against invasive species (Pretty, 2003).
- **Biodiversity Conservation:** Implement targeted conservation programs to protect endemic bird species and other wildlife. This can include habitat enhancement and protection measures that support eco-tourism and biodiversity (Júnior et al., 2021; Aloo et al., 2013)
- **Policy and Economic Incentives:** Develop policies that incentivize sustainable tourism and resource use in the Central Rift Valley. Economic incentives could encourage businesses and individuals to adopt practices that minimize environmental impact and promote eco-tourism (Patel, 2012).

By adopting these recommendations, the Central Rift Valley can safeguard its natural beauty and tourism potential while preserving its rich biodiversity. This will ensure the region continues to contribute positively to local and national economies.

#### ***4.3.4 The Impact of Water Hyacinth on Fishery Production in Lake Dembel***

The fishery sector is a complex and multi-faceted industry that encompasses a diverse array of stakeholders, including fishermen, local collectors, aggregators, and transporters, gillnet makers, boat builders and maintainers, as well as hotels, restaurants, and household end-users. Each of these players is integral to the fish value chain, contributing to the socio-economic fabric of the regions they operate in. However, the pervasive spread of water hyacinth (*Eichhornia crassipes*) has emerged as a significant threat to this ecosystem, with its impact resonating across the entire fishery value chain. Without effective management strategies, the livelihoods of approximately 150,000 individuals involved in this sector are at risk (Dagne, 2017; Abba and Sankarannair, 2024)

Water hyacinth has become a formidable adversary to fishery production and marketing in Lake Dembel. The lake's fish stocks, already under pressure from overharvesting and overcrowding of fishermen, are further threatened by this invasive species. The situation is exacerbated by existing anthropogenic factors that continue to deplete fish production (Asmare, 2017). Discussions with stakeholders reveal that the infestation of water hyacinth has resulted in a significant decline in fish collection, with Focus Group Discussion (FGD) participants estimating a reduction of more than 40%. Similarly, Household (HH) survey respondents reported a 47.34% decline in fish production following the weed's invasion.

The economic repercussions of water hyacinth invasion are profound. Prior to the invasion, household's dependent on fishery activities earned an average of USD 297.3 annually from fish catches. Post-invasion, this figure has plummeted to USD 140.8, a decline corroborated by FGD and Key Informant Interview (KII) estimates. The total economic valuation report by the FDRE Environment, Forest, and Climate Change Commission previously estimated Lake Dembel's fishery potential at USD 1,526,185.3 per year. However, considering the 45% reduction in production reported by FGD discussants and HH respondents, the economic loss attributed to water hyacinth infestation is approximately USD 686,396 annually (Jebitok, C., et al., 2013).

The increased cost of fishing, driven by the proliferation of water hyacinth, exacerbates the plight of fishermen. This aligns with studies conducted in other Ethiopian lakes such as Chamo, Abaya, and Tana, as well as Lake Victoria in Kenya and Uganda (Zekarias and Gelaw, 2023; Damtie et al., 2022). Specifically, water hyacinth has shortened the lifespan of essential fishing tools like reed boats and gillnets, increasing operational costs.

The invasive water hyacinth poses a grave threat to the fishery production and socio-economic stability of communities reliant on Lake Dembel. Its impact is evident in the significant decline in fish production and increased operational costs, leading to substantial economic losses.

To mitigate the adverse effects of water hyacinth, it is crucial to implement integrated management strategies. These should include the physical removal of the weed, biological control measures, and community engagement in sustainable fishing practices (Hill et al., 2020). Enhancing awareness and capacity-building initiatives among stakeholders can bolster collaborative efforts in managing this invasive species. Furthermore, investment in research to develop effective control technologies and strengthen policy frameworks is essential (Yara, 2019).

By addressing these challenges through coordinated and sustainable efforts, the resilience of Lake Dembel's fishery sector can be restored, safeguarding the livelihoods of those dependent on this vital resource.

## 4.4 Conclusion

This study highlights the severe environmental challenges besetting Lakes Koka and Dembel, driven by nutrient pollution and the aggressive spread of water hyacinth. Both issues are symptomatic of broader ecological mismanagement, with nutrient pollution primarily stemming from agricultural runoff and industrial effluents leading to elevated levels of nitrogen and phosphorus. Lake Koka, in particular, suffers from higher nutrient loads and more pronounced eutrophication, while Lake Dembel benefits from some dilution due to its larger volume. These nutrient levels surpass critical thresholds, posing significant threats to aquatic ecosystems and water quality.

The unchecked proliferation of water hyacinth further compounds these challenges, disrupting land use and land cover, impairing water quality, and threatening biodiversity. Its dense mats hinder fishing, navigation, and recreational activities, leading to economic and social disruptions within local communities. The altered hydrology and reduced fishery yields underscore the profound socio-economic impacts of this invasive species, which also detracts from the region's tourism potential.

This situation demands an urgent and coordinated response. Addressing nutrient pollution requires the implementation of sustainable agricultural practices and the upgrading of wastewater treatment facilities. Simultaneously, managing the spread of water hyacinth necessitates an integrated approach, combining mechanical, biological, and chemical control methods within a comprehensive wetland management strategy. Community engagement, education, and local empowerment are crucial to fostering sustainable practices and ensuring long-term ecological balance.

Ultimately, preserving the ecological integrity of Lakes Koka and Dembel hinges on a multifaceted strategy that incorporates stringent monitoring, regulatory enforcement, and adaptive management practices. By engaging stakeholders across sectors and encouraging collective action, it is possible to mitigate the detrimental impacts of nutrient pollution and invasive species, thereby safeguarding these freshwater ecosystems for future generations and supporting the socio-economic well-being of the communities that depend on them.

# Chapter 5: Water Hyacinth Invasion: Implications for Livelihoods in the Central Rift Valley of Ethiopia

## Abstract

*Water hyacinth spans extensive geographic areas in tropical and semi-tropical regions. Its impact on livelihoods is connected to the production of crops, fish, livestock, and other activities that influence costs and returns for rural smallholders. This invasive weed affects crop production by invading farmland adjacent to the lakes and also has an impact on livestock by covering grazing land meant for animal feed. Although several studies have been conducted in Ethiopia, the livelihood impact of water hyacinth has been scarcely analyzed, quantified, and documented. This study evaluates the adverse effects of water hyacinth, particularly on crop production, livestock management, fish harvesting, and other off-farm incomes by comparing groups of respondents' proximity to Lake Koka and Demel in the Central Rift-valley of Ethiopia before and after a specified period. Data were collected from 348 sample households from May to June 2024 based on the nearness of-farmlands to the lakes both adjacent to ( $\leq 300m$ ) and distant from invaded lakes, six focus group discussions, six key informant interviews and field observations to assess the impact using Propensity Scores, Difference-in-Differences, and Weighted Least Squares methods. The result of Difference-in-Differences shows a decline in the total annual income by 823 ETB, income from crop production by 329 ETB per year, and income from off-farm activities by 6952 ETB per year for those living adjacent to the invaded lakes. Although the impact varies according to the intensity of the water hyacinth infestation, it adversely affects rural livelihoods by reducing crop yields and returns from off-farm activities. The study found no significant impact on livestock production and harvested fish. Other control variables such as education, experience, and interactions like dependency-age, experience-education, and land-lake also influenced the livelihood impact. As hypothesized, water hyacinth has caused differences in on-farm and off-farm incomes between groups of respondents. Further research is suggested to investigate the fish species favored and affected by this invasive weed. Ultimately, the impact of water hyacinth is of significant interest to affected communities, regional offices, policymakers, and scientists.*

**Keywords:** Water hyacinth, Livelihood impact, Crop production, Off-farm incomes, Invasive species and Ethiopia

## 5.1 Introduction

Water hyacinth is one of the invasive aquatic and wetland species that cover extensive geographic areas in tropical and semi-tropical regions (Kriticos and Brunel, 2016; Pan et al., 2015). It inhabits both water bodies and terrestrial environments (Simberloff, 2013). Water hyacinth presents both opportunities and challenges to socio-economic activities and the environment. It can be utilized as an input in agricultural activities, as well as in the manufacturing and industrial sectors, to produce paper, furniture, biogas, and ethanol (Sharma and Aggarwal, 2020), and various household products (Maulidyna et al., 2021).

The impact of water hyacinth is closely linked to rural livelihoods, including crop, fish, and livestock production, as well as input supply and the cost of management and maintenance. In terms of crop production, it impedes rice seed germination (Mathur and Mathur, 2018), reduces crop yield (Enyew et al., 2020), and consequently lowers returns (Maulidyna et al., 2021). Similarly, the weed affects the food supply by reducing fish populations (Harun et al., 2021) and fish supply (Kateregga and Sterner, 2009). Moreover, water hyacinth negatively impacts the livelihoods of farmers and traders involved in fish marketing (Segbefia et al., 2019) by disrupting business operations (Ezama, 2019). This invasive weed also restricts access to fishing areas, which increases production costs and creates supply shortages (Villamagna and Murphy, 2010). The time required to catch fish has increased due to obstructed boat passages (Harun et al., 2021), limiting fishing grounds (Villamagna and Murphy, 2010). In this context, the maintenance costs of blocked ditches and canals have become high (Dersseh, Melesse, et al., 2019).

The impact of water hyacinth in Ethiopia has been reported in relation to crop production (Damtie et al., 2022; Enyew et al., 2020), where it competes for water resources (Getahun and Kefale, 2023) and disrupts production activities (Enyew et al., 2020). It challenges plowing activities (Getahun and Kefale, 2023; Tewabe et al., 2017), resulting in increased costs and time expenditure (Getahun and Kefale, 2023). Similarly, water hyacinth affects livestock and feed production (Getahun and Kefale, 2023; Tewabe et al., 2017), invades grazing lands (Tewabe et al., 2017), and creates a shortage in the feed supply (Enyew et al., 2020). The use of water hyacinth as feed can also lead to livestock fatalities related to its content (Damtie et al., 2022).

Water hyacinth also disrupts fishing activities and reduces the harvesting rate (Damtie et al., 2022; Dersseh et al., 2019; Delele et al., 2021) leading to a decrease in the quantity of fish caught (Enyew et al., 2020; Tewabe et al., 2017). Furthermore, it incurs high costs for weed management (Damtie et al., 2022; Getahun and Kefale, 2023) and the maintenance of ditches and canals (Derss et al., 2019).

Several studies and literature reviews have been conducted on water hyacinth in Lake Tana, Lake Dembel, Lake Koka, and Aba Samuel Dam in Ethiopia. Most studies on Lake Tana focus on the effects of water hyacinth; Tewabe et al., (2017), perceptions of its impact (Enyew et al., 2020), its infestation potential (Dersseh et al., 2019), and its ecological, economic, and social implications (Getahun and Kefale, 2023), as well as its impact on rural livelihoods (Damtie et al., 2022). In contrast, only a few studies on Lakes Dembel and Koka and Aba Samuel Dam emphasize socioeconomic and environmental sustainability (Churko et al., 2023), water quality (Getnet et al., 2021), and its impact on aquatic life and human activities (Ingwani et al., 2010). However, these studies have scarcely analyzed, quantified, and documented the livelihood impact of water hyacinth in Lake Dembel and Lake Koka, and in Ethiopia more broadly.

Therefore, this study aims to assess the livelihood effects of water hyacinth. Specifically, it addresses the impact of water hyacinth on crop production, livestock management, and fish harvesting by comparing affected and non-affected households before and after a specific period. It is hypothesized that the weed would cause differences in income and Tropical Livestock Unit (TLU) between households adjacent to and away from the lakes. The output of this research will contribute to the invasive weed management policies formulation in the Central Rift Valley and Ethiopia as a whole. Additionally, the recommendations will help bridge knowledge gaps in understanding the livelihood impact of water hyacinth.

## **5.2 Methodology**

### **5.2.1 Sampling procedure and sample size**

This study was conducted in three districts, Lume, Dugda, and Adami Tulu Jido Kombolcha in the East Shewa Zone of the Oromia Regional State, Ethiopia. Zone and districts were purposively selected due to the threats of water hyacinth, where Lake Dembel and Koka exist. These lakes are among the foremost water bodies that provide several socio-economic benefits to the local people, in particular, and to the surrounding areas, in general, including the capital city (Addis Ababa). Kebeles<sup>1</sup> were randomly selected considering their common boundaries to lakes and the level of water hyacinth invasion. In this case, a list of Kebeles with high water hyacinth (where the whole shoreline of the lakes is covered by the weed) and no water hyacinth infestation was identified through discussion with experts working on water hyacinth management in Lume, Dugda, and Adami Tulu Jido Kombolcha districts. In addition, the sites were verified by field visits to the study area. From the list, six Kebeles were selected from Lume, six from Dugda, and four from Adami Tulu Jido Kombolcha. Based on the proximity of individual

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<sup>1</sup> Kebele is the lowest administration level next to District in the study areas.

households within the kebele, the respondents were grouped as adjacent (who conducted agricultural activities up to 300 meters from the lakes) and not adjacent to water hyacinth-invaded lakes (who are conducting agricultural activities 300 meters away from the lakes). The total sample size of households was determined by Eqn. 5.1.

$$n_0 = \frac{N}{1+N(e)^2} \quad 5.1$$

Where =  $n_0$  is sample size;  $N$  is the total number of households, and  $e$  is the level of precision (in this case 0.05). Based on the data obtained from the Environmental Protection and Agricultural Development offices of the districts, the total number of households of selected kebeles were 8654. Accordingly, the sample size is 382 considering the probability that some of the respondents might not be available for interview or refuse to be interviewed, 5% of sample (18) households were added to make the total sample 400.

The proportionate sampling technique is employed to determine the sample size from each kebele. Sample households adjacent and not adjacent to invaded lakes were systematically selected by interval and lottery methods. After following the first sample drawn, every  $k^{\text{th}}$  element in the list was selected until the proportion number reached from all sample Kebele. In the Lume district, 125 samples were selected, 61 are adjacent and 64 are nonadjacent to the lake. Similarly, from the total 119 samples selected from Dugda, 78 are adjacent and 41 are not adjacent. Likewise, from 102 samples selected from Adamitulu Jidu Kombolcha, 41 are adjacent and 61 are not adjacent to the invaded lake.

### **5.2.2 Data type and collection**

The type of data required to address this research is fully quantitative cross-section data collected from the samples adjacent and not adjacent to lakes using a structured questionnaire. Primary quantitative data were collected from sample households using a structured questionnaire. The questionnaire is managed and collected by using the Kobo toolbox (<https://eu.kobotoolbox.org/#/projects/home>). One supervisor and four data collectors were recruited, and training was given. The data is collected from sample respondents in a house-to-house-based face-to-face interview for three weeks from May 12 to June 15, 2024. To triangulate the information all data gathered through household interviews were supported by related annual and periodic reports and published articles. In addition, key informant interviews were held at the Federal, regional and district levels by engaging experts and individuals with experience in water hyacinth management. Furthermore, the study conducted focus group discussions in which 6–8 focus group discussants were engaged considering educational background, experience in water hyacinth management, status in the community and other social values of the community. Therefore, data for this

research work was obtained from the households, focus group discussions (FGD) and Key informant interviews (KII).

### 5.2.3 Method of Data Analysis

Descriptive and econometric models are employed to address the impact of water hyacinth. Descriptive analysis was used to compare demographic and socioeconomic variables for individuals grouped into adjacent and not adjacent to the nearby Koka and Dembel lakes. It is also compared based on before and after the expansion of the weed in two periods. The data are described by mean, frequency, and percent. To validate the result, inferential statistics such as t-test and chi-square were applied. The impact was assessed using Propensity Score Matching and Difference in Difference between the two sample groups. These methods were preferred among others to see their difference in livelihood due to the water hyacinth invasion. The counterfactual is constructed by modeling the relation between dependent livelihood variables, independent variables, and grouping variables in a regression analysis.

### 5.2.4 Propensity Score Matching

Similarity between individuals adjacent to the invaded lake and not invaded is identified by plotting the propensity score (PS). If the plots overlap between the two groups, there is strong evidence for the common support (similarity of propensity scores). It can be done using Kernel matching (Fig 24) among other methods due to its comparison of each individual adjacent to the invaded lakes to the control (far from invaded lakes) within a particular range of PS. If the common support assumption holds it is possible to run PSM which has an advantage over Ordinary Least Square in producing consistent estimates under weak conditions.

The propensity score is computed by regressing the intervention variable by observable characteristics (Khandker et al., 2010). The model is expressed in Eqn. 5.2 as:

$$I_i = B_0 + B_1 X_i + \epsilon_i \tag{5.2}$$

where  $I_i$  is the  $i^{\text{th}}$  respondent located in the nearby invaded lake ( $I_i$ ) or not,  $B_0$  and  $B_1$  are parameters,  $X_i$  is the observable demographic and socioeconomic characteristics;  $\epsilon_i$  is the random error term. It can be expanded as (Eqn. 5.3):

$$I_i = f(B_0 + B_1 X_1 + B_2 X_2 + \dots B_n X_n + \epsilon_i) \tag{5.3}$$

The predicted  $I_i$ ,  $B_0$ , and  $B_1$  is given by Eqn. 5.4.

$$\hat{I} = \hat{B}_0 + \hat{B}_1 X_i \tag{5.4}$$

Hence, the PS is the predicted probabilities from a Probit/ logit model of the invaded variable regressed on independent variables, expressed by Eqn. 5.5.

$$P(I_i = 1/X) = \hat{I} = \hat{B}_0 + \hat{B}_1 X_i \quad 5.5$$

Eqn. 5 can be further expanded to (Eqn. 5.6.):

$$\hat{I} = f(\hat{B}_0 + B_1 X_1 + B_2 X_2 + B_3 X_3 \dots B_n X_n) \quad 5.6$$

Before describing the economic impact of water hyacinth, propensity score matching (**PSM**) is done between the respondents living adjacent and not adjacent (control group) to the lake. The observable variables such as age, marital status, education, farmland, experience, dependency ratio, and livestock ownership are expected to affect the income level. So, the PSM result was used before estimating the DID impact on the total income, farm income, off-farm income, fish income, and TLU. Specifically, we ran PSM on the two groups and assured the validity of the common support assumption. As shown in Figure 21, the kernel matching result reveals that individuals adjacent to the invaded lake are matched to the control groups with more similar propensity scores. This result is evident to precede the impact of water hyacinth comparing the different livelihoods before the expansion of the weed in 2018 as a reference year and after five years in 2023 between the two groups.

### 5.2.5 Difference in Difference

Difference in Difference (DID) is a quasi-experimental design that makes use of data from two sample groups to obtain an appropriate counterfactual to estimate a causal effect. It compares the average difference between individuals located adjacent to and far from the invaded lake, based on outcome changes over time relative to pre-invasion of the weed. Given the two periods ( $t_1$ ), (2018 ( $t_0$ ) and 2023 ( $t_1$ )),  $Y_{it}^{11}$  and  $Y_{it}^{10}$  are the respective outcome (livelihood) variables for both groups in time  $t_i$ , the DID is estimated the impact of water hyacinth invasion as follows:

$$DID = E(Y_{t1}^{11} - Y_{t0}^{11}) | I_i = 1) - E(Y_{t1}^{10} - Y_{t0}^{10}) | I_i = 0) \quad 5.7$$

In the above equation (Eqn. 5.7)  $I_i = 1$  denotes individuals adjacent to the invaded lake, whereas  $I_i = 0$  denotes individuals located away from the invaded lake. The DID estimate is conducted using the regression equation (Eqn. 5.8):

$$Y_{it} = \alpha + \beta I_{it} + \rho I_i + \gamma t + \varepsilon_{it} \quad 5.8$$

The coefficient  $\beta$  is the interaction between after weed invasion ( $I_{it}$ ) and time  $t$  ( $t_i= 1$  or  $t_i= 0$ ) gives the average DID effect of the weed. Using the DID estimate from equation 8, the interaction is expressed as,  $\beta = DID$ . In addition, the variables  $I_i$  and  $t$  is included to take any separate average effect of being invaded versus not invaded by water hyacinth and the effect of time ( $t$ ).

## **Variables definition**

Annex 1 of Table 1 summarizes the group, dependent, and explanatory variables. Group variable identifies sample households based on their proximity to the Lakes. It is hypothesized to affect the outcome (dependent) variables. The dependent variable includes income from different sources and livestock production. Explanatory variables are also expected to influence the dependent variable in both groups of respondents.

## **5.3 Results**

### **5.3.1 Description of demographic and socioeconomic characteristics**

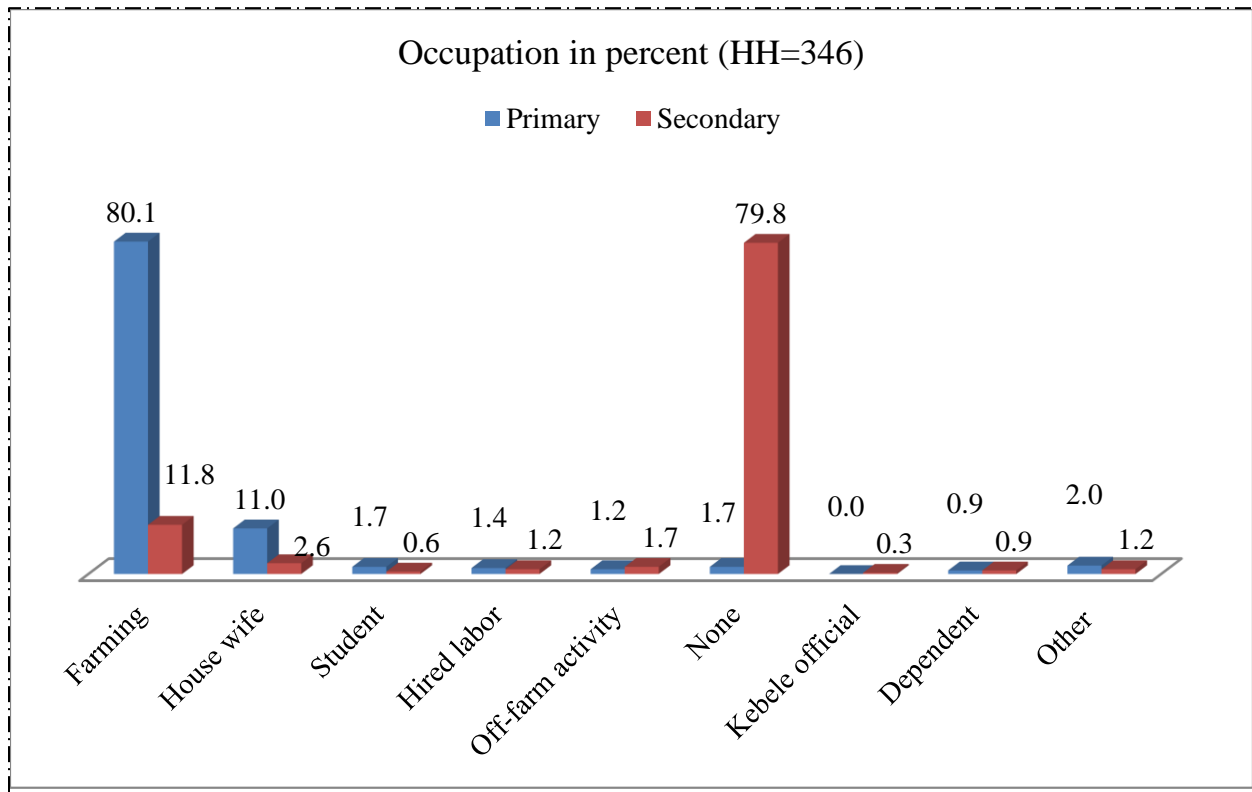
Demographic and socioeconomic characteristics of sample households living in the study area are compared based on their proximity to water hyacinth invaded lakes. Of the total 400 samples, about 87 percent of the respondents were willing to answer questions. Annex 1 of Table 2 shows that a greater number of the sample respondents' farmland is adjacent to the lake (52%), male dominated (78%) and married (81%). Similarly, a large number of the samples have their land (96%), are involved in on-farm activities (78%), and their livelihood depends on the lakes (84%). Yet, except for household heads involved in off-farm activities, all other characteristics are not significantly vary based on whether their farmland is proximate or not to the lakes.

#### **Age, Family size, and Education**

Sample households living in the study area are characterized by their age, education level, family size, dependency ratio, and land holdings (Annex 1, Table 2). The average age of respondents not adjacent to the lake is 45 years, while those who live adjacent to the lake are 44 years old. Similarly, in each group, the average completed education level is two years of schooling. They also have five family sizes with a dependency ratio of one. The average area of farmland is approximately 1.3 ha for both groups of respondents. The result shows there is no significant difference in demographic and socioeconomic characteristics between the two groups.

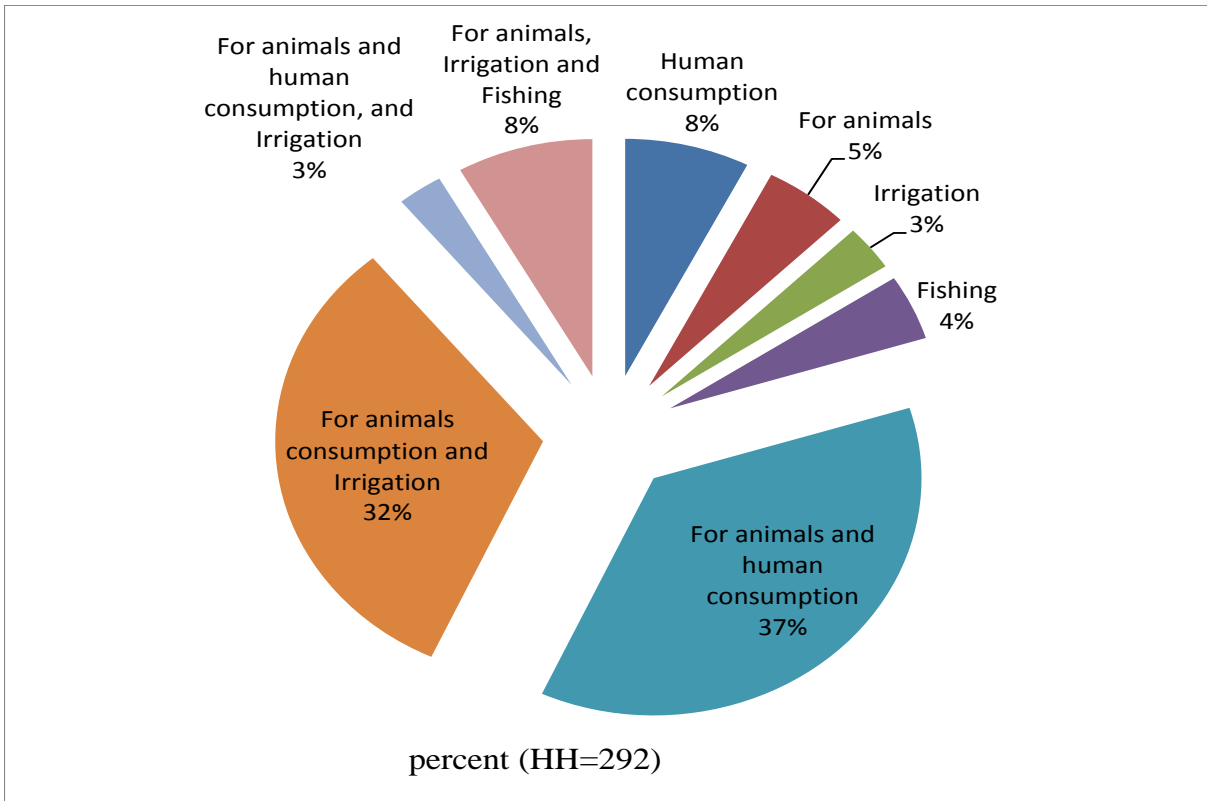
## Occupations of HH

Figure 19 shows the main and secondary jobs of respondents in areas invaded and not invaded by water hyacinth. The dominant primary and secondary occupations of the respondents are farming, 80 and 12 percent, respectively, followed by household wives (11 and 3) and students (2 and 1). Other common occupations are hired labor, off-farm activities, kebele officials, and aged respondents who depend on the family. The remaining 80 percent (276 respondents) do not have a secondary occupation. In this respect, crop production and livestock rearing are the mainstay for the community in the study area. Hence, the lake could have a prominent role in farming activities.



**Figure 19.** Household’s primary (main) and secondary jobs (Source: Own survey 2024)  
**Dependency of-farmers on the Lakes**

Figure 20 presents about 292 sample households (84%) that are dependent on the lakes in their vicinity. They used the lakes for different purposes. The most common uses are for human consumption (8%), animal consumption (5%), fishing (4%), and irrigation (3%). A combination of uses for human and animal consumption (37%), animal consumption and irrigation (32%), and for more than two purposes (11%).

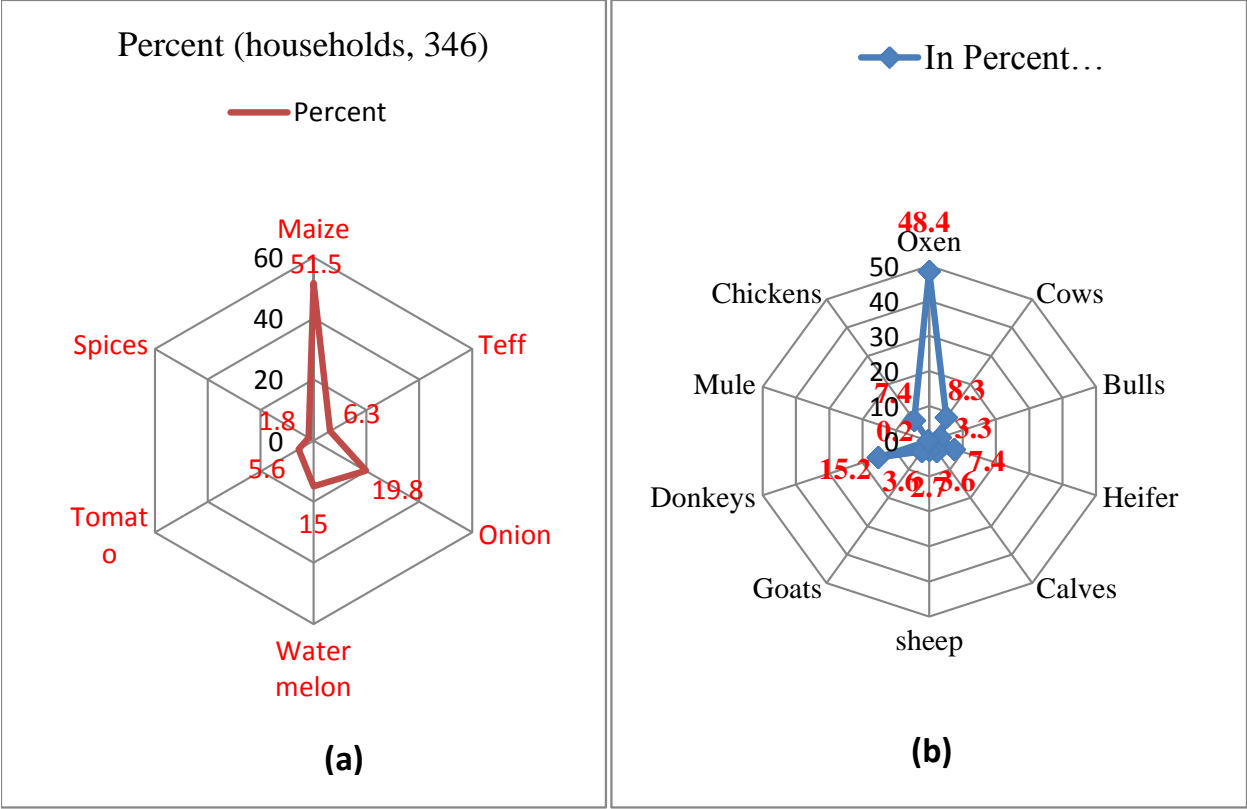


**Figure 20.** Households' dependency on the lakes

### 5.3.2 Economic activities and source of income

#### Types of crops and livestock produced

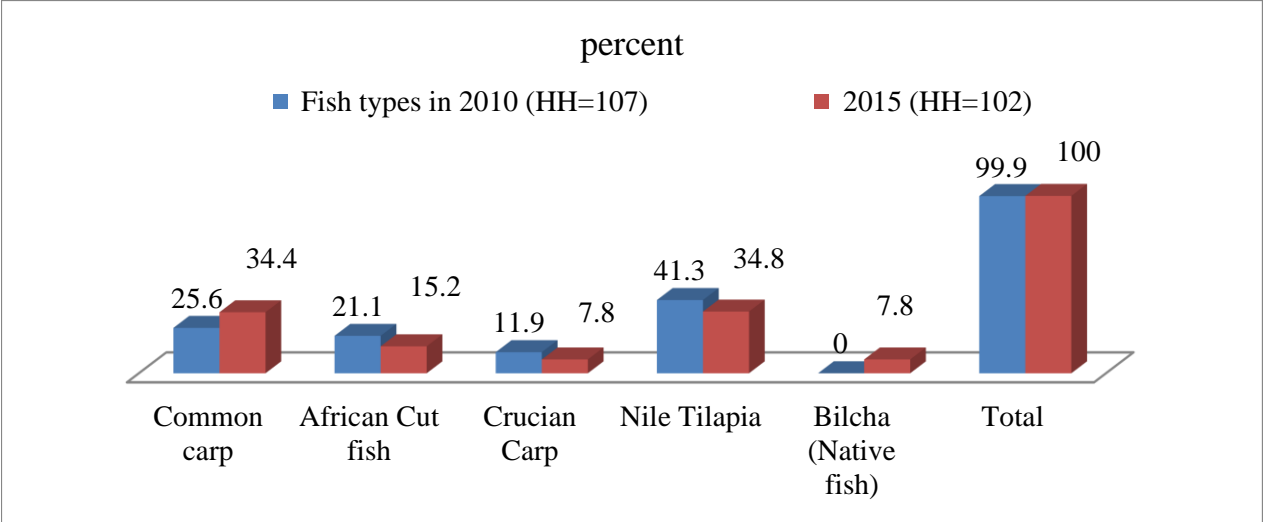
The economic activities of rural households are influenced by several factors. The community in the study area is engaged in on-farm, off-farm, and non-farm activities. The prominent on-farm activities include crop and vegetable production, livestock rearing, and fishing. The major crops produced in the area are maize (52%) and teff (6%) followed by vegetable production such as onion (20%), watermelon (15%), tomato (7%) and spices (2%). Similarly, 79 percent of the respondents owned different livestock for consumption and draft animals. Most of the households' own oxen (48%), donkey (15%), cow (8%), heifer (7%), chicken (7%), and others (15%) like calf, goat, bull, sheep, and mule (Figure 21).



**Figure 21.** Households Crop (a) and Livestock (b) production

**Types and volume of fish harvested**

Fish types found in the lakes are compared in 2018 with 2023 to see whether there is a variation related to the water hyacinth expansion. Of the total respondents, 31 percent in 2018 and 29 percent in 2023 are engaged in fishing activities. According to the respondents engaged in fishing activities, there are five fish species caught in the given periods (Figure 22). Among the species, more HH trapped Common carp and Bilcha (native species) in 2023 as compared to the previous period. The respondents indicated that the number of other species caught declined in 2023 than the previous year. Except for the Curcian Carp, the number of fish caught species increased in 2023 (Figure 18). The average amount of harvested Tilapia (86 kg), African catfish (101 kg), Common carp (100 kg), and Native species (25 kg) per household per year.

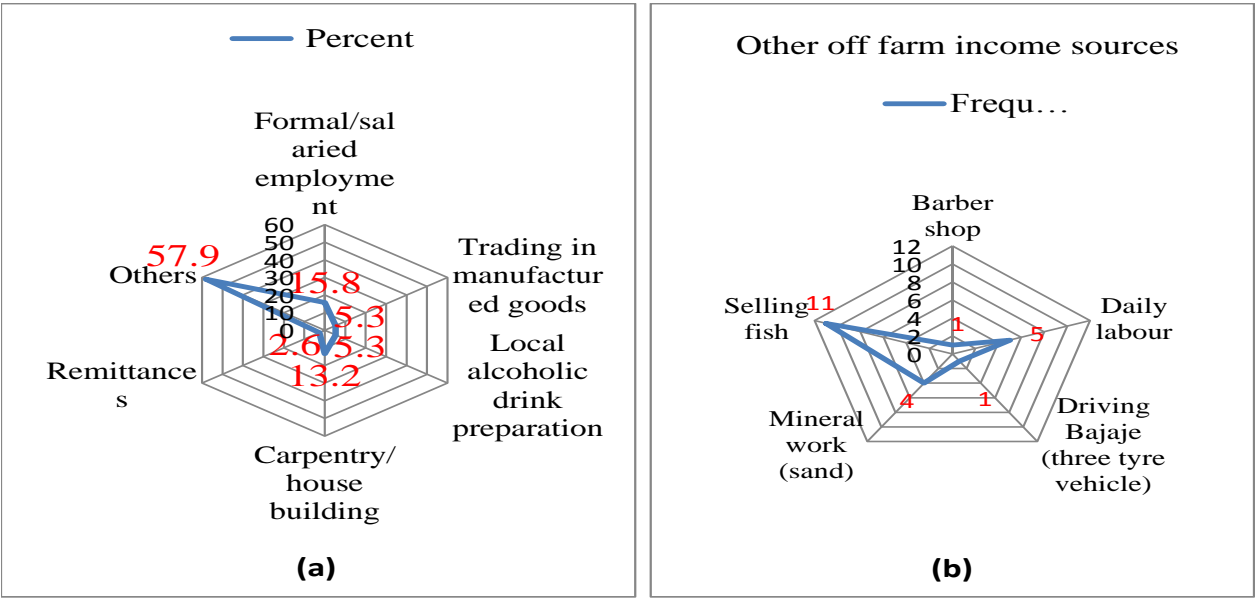


**Figure 22.** Fish species harvested in the Lakes (Source: Own survey 2024)

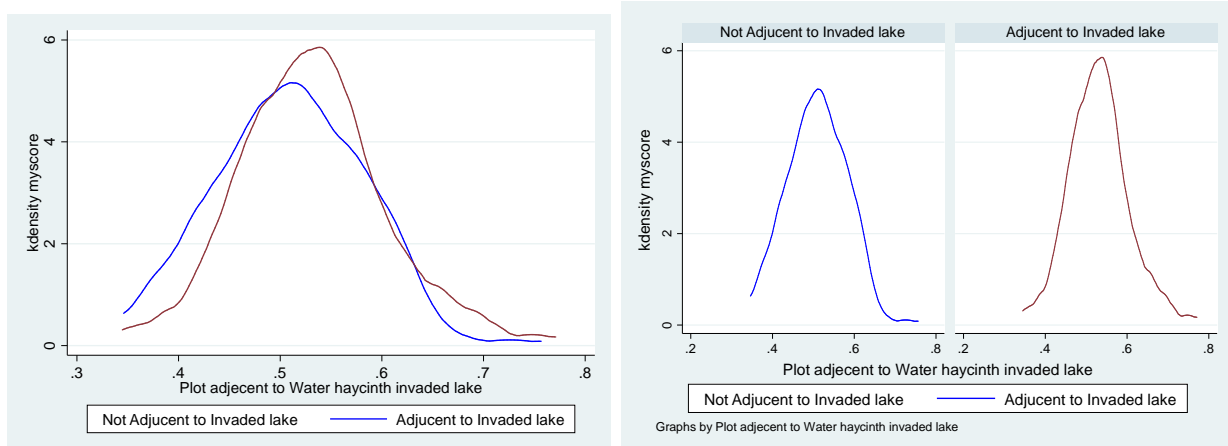
Note: The years indicated in the figure are in Ethiopian Calander where 2010 refers to 2018 while 2015 is 2023 in GC.

**Off-farm income sources**

Of the total respondents (348 HH) only 11 percent (HH=38) are involved in off-farm income generation activities. About 41.3 percent of them (16 HH) were involved in salaried employment, carpenter, local alcohol preparation, trading manufactured goods, and remittance (Figure 23). The remaining 58 percent (HH = 22) were engaged in other off-farm activities such as selling roasted fish, daily labor, and sand mining among others (Figure 23).



**Figure 23.** Sources of off-farm income (Source: Own survey 2024)



**Figure 24.** kernel density plots for common support assumption (Source: Own survey 2024)

### 5.3.3 Impact of water hyacinth on Income and Livelihood

#### Impact of water hyacinth on the livelihood (DID; 2018-2023)

Livelihood variables such as total income, on-farm, off-farm, and fish incomes as well as a number of livestock in terms of TLU are regressed by the two groups (land adjacent to invaded and not invaded land) and other explanatory variables. The outcome variable is the income difference after and before the invasion of the lakes by the weed between the two groups. Table 4 of Annex 1 shows that the model is significant for the DID's of the total incomes at  $P < 5\%$ , on-farm incomes at  $P < 5\%$ , and off-farm incomes at  $P < 1\%$ .

#### Impact of water hyacinth on total DID income

The total annual DID income before and after the invasion is significantly affected by individuals' land adjacent to the lakes, the education level of the respondent, and the interaction between dependency ratio and age as well as land size and Lakes Dembel. Accordingly, the total DID income of those individuals adjacent to the lakes decreased by 822,738 ETB as compared to the non-adjacent households. Similarly, completed education level negatively affects the total DID income. As education increases by one year of schooling, the total DID income declines on average by 129,416 ETB. The other variable that affects the total DID income is the interaction between the dependency ratio and age. As the interaction increases, more dependency and old age, the total DID income declines by 5,690 ETB. Similarly, the interaction of individuals' land in the Dembel Lake area significantly affected the total DID income. An increase in the size of land in Dembel Lake increases the total DID income by 277,104 ETB as compared to land found in Lake Koka.

### **Impact of water hyacinth on on-farm DID Income**

The on-farm annual DID income from crop production, before and after the invasion, is significantly affected by individuals' land adjacent to the lakes, land size, experience, and the interactions between dependency ratio and age as well as land size and Lakes Dembel. Accordingly, the on-farm DID income of those adjacent to invaded lakes decreased by 329,038 ETB as compared to non-adjacent households. Likewise, household land size negatively affects the on-farm DID income. As the land increases by one hectare, the on-farm DID income declines by 113,019 ETB. Individuals' experience in agricultural land use is the other variable that affects the on-farm DID income. The result shows that per unit increase in experience, the on-farm DID income declines by 10,724 ETB.

The interaction between the dependency ratio and age is also a determinant of on-farm DID income. More dependency ratio and old age interaction decrease the on-farm DID income by 2,986 ETB. Unlike the above result, the interaction of individuals' land in the Dembel Lake area positively contributed to the on-farm DID income. An increase in the size of land in Dembel Lake increases the on-farm DID income by 182,891 ETB as compared to land found in Lake Koka.

### **Impact of water hyacinth on livestock size and off-farm DID income**

The DID households' livestock size in TLU in both invaded and not invaded areas is insignificant. This suggests that the influence of water hyacinth is not noticeable in the invaded areas as compared to the other areas. Rather control variables such as knowledge about the water hyacinth determine the TLU. Households being knowledge about the weed, their livestock size declines by 0.707 TLU as compared to others.

The off-farm DID income before and after the invasion is significantly affected by individuals' land adjacent to the lakes, age, land size, and the interactions between dependency ratio and age as well as land size and Lakes Dembel. Accordingly, the off-farm DID income adjacent to invaded lakes decreases by 6,952 ETB per year as compared to households not adjacent to the invaded lake.

The age of the respondent and land size positively determine the annual off-farm DID income. Accordingly, as the age increases by one year the off-farm DID income increases by 192 ETB. Also, as the land increases by one hectare, the off-farm DID income increased by 2,939 ETB. The other variable that affects the off-farm DID income is the interaction between the dependency ratio and age. With an increase in the interaction, the off-farm DID income increases by 63 ETB. Unlike the dependency and age interaction, the land and Dembel Lake interaction decreases the off-farm DID income. An increase in the size of land in Dembel Lake decreases the off-farm DID income by 3,419 ETB as compared to land found in Lake Koka.

### **Impact of water hyacinth on the livelihood (in 2023)**

Livelihood outcome variables such as total income, on-farm, off-farm, number of livestock in terms of TLU and fish incomes are regressed to examine the impact of water hyacinth. Table 5 of Annex 1 shows the weighted least square (weighted by farmland) with robust standard error. The model is significant for the total incomes at  $P < 5\%$ , on-farm incomes at  $P < 1\%$ , TLU at  $P < 5\%$ , and off-farm incomes at  $P < 1\%$ .

### **Impact of water hyacinth on the total income**

The total annual income of households located in the invaded land is significantly affected by water hyacinth, education level, and interactions between dependency ratio and age as well as land and the lakes. Accordingly, the total income of those individuals adjacent to the lakes decreases on average by 748,844 ETB as compared to the non-adjacent households. Similar to the total income, completed education level negatively affects the total income. As a result, with an increase in education by one year of schooling, the total income declines on average by 98,830 ETB. The other variable that affects the total income is the interaction between the dependency ratio and age. As the interaction increases by one unit, the total income declines by 4,732 ETB. Similarly, the interaction between land and Dembel Lake significantly affects the total income. An increase in the land size by one unit in Dembel Lake increases the total income by 280,454 ETB as compared to land found along Lake Koka.

### **Impact of water hyacinth on on-farm income**

Unlike the total annual income, the on-farm income in 2023 is similar between individuals found adjacent to and far from invaded lakes. Other control variables such as education, experience, land size, and the interactions between land size and Lake Dembel, significantly determine the total income. Accordingly, an increase in education by one year of schooling increases the farm income by 2,258 ETB. An increase in experience and land size also leads to a decline in income by 367 and 2,457 ETB, respectively. Likewise, as the interaction of land and Dembel Lake increases, the on-farm income declines by 1082 ETB as compared to the interaction of land and Koka Lake.

### **Impact of water hyacinth on livestock size and off-farm income**

Households' livestock size in TLU in the invaded and not invaded areas is the same. This suggests that the influence of water hyacinth is not significant in the invaded areas as compared to the other areas.

Rather, control variables such as education, experience, interactions of dependency ratio with age, and experience with education are the determining factors. Thus, an increase in education level, experience,

dependency ratio, and age interaction increases TLU by 0.203, 0.0395, and 0.006 units, respectively. Yet, the increase in interaction between experience and education decreases TLU by 0.009 units.

Off-farm household income in the invaded and not invaded areas are also the same. This suggests that the influence of water hyacinth is not significant in the invaded areas compared to the other areas. Rather, control variables such as the dependency of the household livelihood on the lake is determining factor. The household dependency on the lakes is the sole control variable that determines the off-farm income. Those individuals perceived their livelihoods are dependent on the lakes, their off-farm income increases by 28,489 ETB as compared to others not dependent on the lakes.

### **Impact of water hyacinth from the viewpoint of FGD and KII**

Focus Group Discussions (FGD) show that the weed adversely affects the economic and social life of the surrounding communities whose livelihoods are based on fishery resources and agricultural activities. Among other economic activities fishery and agriculture were the major sectors influenced by infestation of water hyacinth. They added that not only the farmers but also traders found along the value chain are affected (FGD 2). Similarly, other discussants (FGD 3) reflected its impact on crop production activities through blockage of canals and decreasing fish productivity. They stressed that its impact is severe on the livelihood of communities solely dependent on the lakes for fish and agricultural production (FGD3). Furthermore, farmers incur additional costs of removing the weeds from their farmland, and their family forced to spend more time (FGD4).

Key Informant Interview (KII) was conducted at the national and regional levels to crosscheck the findings. Accordingly, the first respondent about the impact of water hyacinth said that "... crop production nears the shoreline, fishing, fish breeding grounds, and livestock feed..." were the most affected sectors (KII 1). He added that "...During our field observation ... the quantity of fish caught per day after water hyacinth expansion, was lower than pre-water hyacinth occurrence...". The other key informant also added that "...Water hyacinth infestation has significant impacts on local communities, particularly those reliant on fishing and agriculture" (KII 3). He also added that "...water hyacinth infests irrigation channels or reservoirs; it can block the flow of water, impacting the ability to irrigate crops. This can lead to reduced agricultural yields and increased labor for farmers trying to manage the infestation." Similarly, KII 4 said that "water hyacinth affects the livelihood of this community by invading their farmland and expose them for other additional cost and minimize the fish product that collected from the lake by affecting the living area of fish" (KII 4). Furthermore, the impact of water

hyacinth expressed as “... in water hyacinth covered area fishing is difficult.”, “... fishing nets trapped by water hyacinth destroyed...” (KII 5) and it “... Block irrigation channels and hinders irrigation practices..., reduce access to water for livestock...” (KII 6).

## **5.4 Discussions**

### **Impact of water hyacinth on household income**

Quantifying the impact of water hyacinth is a critical footstep in reducing the negative consequences on income and food security in developing countries. From the result in section 5.3, there is a significant difference in the households’ income adjacent and not adjacent to the lakes. The water hyacinth invasion declined the total and on-farm incomes of households adjacent to the Lakes. Although water hyacinth infestation hampers the on-farm income by reducing crop yield (Honlah, Segbefia, et al., 2019), the impact varies according to the intensity of the weed (Villamagna and Murphy, 2010).

Controlling weed competition for nutrients and light (Horvath et al., 2023) increases the yield of wheat (Minhas et al., 2023), maize (Ali et al., 2011), and soybean among others (Sepat et al., 2017), which is expected to increase the on-farm return. On the other hand, crop yield reduces due to failure to control water hyacinth (Damtie et al., 2022) and blockage of the irrigation canals (Churko et al., 2023; Maulidyna et al., 2021). Similarly, land covered by the weed completely reduced farmers' return (Tewabe et al., 2017) and even smallholders incur additional costs of production (Churko et al., 2023; Getahun and Kefale, 2023). Invasive weeds are also a habitat for other invasive species which pose adverse effects on agricultural production and productivity (Pratt et al., 2017). In this regard, controlling the expansion of water hyacinth would be crucial for the betterment of households’ livelihood in the Lakes.

### **Impact of water hyacinth on household off-farm income**

In developing countries, smallholder farmers are engaged in off-farm activities to diversify their household income (Adeoye et al., 2019; Liu et al., 2019). Off-farm income, comparable to the on-farm, has contributed to food security and poverty reduction for the smallholders (Babatunde and Qaim, 2010). Taking into account its role, households’ off-farm income in the study area is directly or indirectly associated with the Lakes. Some of the incomes linked to Lakes are selling fried fish, daily labor engaged in vegetable production, and sand mining. Other incomes that are not related to the lakes are salary, trade, local beverage sales, remittance, and carpentry work. Yet, the off-farm income declined for households adjacent to the invaded lakes as compared to the other group of respondents.

Water hyacinth has the advantage of generating income rather than solely concluding it as a dangerous invasive weed. The weed has an opportunity to enhance household income by using it as an input for

making handicrafts (Harun et al., 2021), biogas (Wang, 2021), and compost among the benefits (Muhsin et al., 2023; Nega et al., 2022). Hence, measures to control water hyacinth should consider its diverse economic and environmental benefits.

### **Impact of water hyacinth on livestock and fish production**

Many have been said about the livelihood role of livestock for the smallholder in relation to food security and poverty reduction. Like income from on-farm crop production, it is the main source of income for most smallholders (Ashley et al., 2018), the mainstay of livelihood (Chaminuka et al., 2014), and contributes to the economy of a developing country (Herrero et al., 2013). In relation to water hyacinth, this study could not find any significant impact on livestock production between invaded and non-invaded areas. There are some assumptions about the livelihood of the study area. First, the farming system, households in the area are more dependent on vegetable and crop production. Second, feed sources, if the livestock feed is other than grazing land, the weed may not have a significant impact. Lastly, the size of land and herd, if households have no enough grazing land and a significant number of livestock size, it may happen. In sum, it is against some finding (Chapungu et al., 2018; Ogunlade, 2002). For instance, Tewabe et al., (2017) found that the weed influenced livestock production by invading the grassland. Rommens et al., (2003) investigated its impact on feed supply and Damtie et al. (2022) showed its cause on livestock death.

In a similar manner to the livestock, fishery too has a marked contribution to the livelihood (Temesgen M. et al., 2019) and food security (Funge-Smith and Bennett, 2019; Lauria et al., 2018). Our findings show water hyacinth has no significant impact on fish income in the invaded areas. Since the harvested fish species in the study area varies due to water hyacinth, it may or may not affect the total amount of fish caught (Segbefia et al., 2019). Some studies revealed that water hyacinth increases the conducive environment for fish species like killifish (Hill J. M. et al., 2021). As explained in the result, the weed had some effect but not significant. In contrast, some reports show that water hyacinth has increased the cost of production and shortage of supply in the market (Villamagna and Murphy, 2010), declines the amount of fish harvested (Enyew et al., 2020e; Tewabe et al., 2017), and disorder the fish business (Ezama, 2019; Ogunlade, 2002) consequently lead to income decline.

## **5.5 Conclusions and Recommendations**

This study has meticulously analyzed and quantified the livelihood impact of water hyacinth in Lake Dembel and Lake Koka. These areas are of significant interest to affected communities, regional authorities, policymakers, and scientists. The results of this study are relevant beyond the immediate

study area and upscalable to other regions where water hyacinth also poses a similar challenge. Several important issues emerge from the findings.

First, from a methodological perspective, the households in invaded and non-invaded areas were balanced for the common support assumption before analyzing the impact using Difference-in-Differences (DID) and Weighted Least Squares regression. This methodological rigor provides evidence of an unbiased impact of water hyacinth on both on-farm and off-farm incomes.

Second, the impact of water hyacinth is not solely attributable to the weed itself; other control variables such as education, experience, and interactions like dependency-age, experience-education, and land-lake also influence the impact. This highlights the multifaceted nature of the issue and the need to consider various socio-economic factors when assessing the impact of invasive species.

Third, as hypothesized, water hyacinth has caused a significant difference in on-farm and off-farm incomes between groups of respondents. Contrary to the hypothesis, the study found an insignificant impact on livestock size and fish income. This discrepancy suggests that the invasive weed effect on different livelihood components may vary and warrants further investigation.

Finally, it is crucial to conduct a thorough analysis of the communities' pro-environmental perceptions regarding water hyacinth and the ecology of fish in the affected lakes. Such analyses are essential not only for understanding social behavior and fish ecology but also for investigating which fish species are favored or adversely affected by this invasive weed.

This research underscores the complex and varied impacts of water hyacinth on rural livelihoods in Lake Dembel and Lake Koka. Since vegetable and crop productions are the mainstay for the livelihood of most HHs' along the rivers and lakes, these findings serve as a valuable input for formulating invasive weed management policies in the Central Rift Valley and in Ethiopia at large.

The following recommendations will help bridge knowledge gaps and provide a foundation for future research on the livelihood impacts of water hyacinth and other invasive species.

- ✓ Community mobilization and awareness creation on the impact of water hyacinth on livelihood and different ecosystem services needed for the management and control of the weed and sustainability of the lakes.
- ✓ Resource mobilization for the control and management of water is needed by the local, regional and federal governments of Ethiopia.

- ✓ Both lakes (Koka and Dembel) provide multipurpose uses including hydropower generation, fish production, irrigation, and flood control and are sources of water for livestock and humans benefiting different stakeholder groups. Hence, conservation of the lakes needs coordination and collaboration among different stakeholder groups at different levels.
- ✓ The need for multidisciplinary research: this research is limited to the impact of hyacinth on crop production, livestock management, and fish harvesting by comparing affected and non-affected households before and after a specific period. To comprehensively assess the effect of the weed on the livelihood of the households, further research should be carried out on the utilization of water hyacinth for different purposes. Furthermore, research is needed on which fish species are favoured and affected by water hyacinth.
- ✓ Focus group discussion and key informant interviews conducted for this study revealed that manual removal of water hyacinth is the common approach in the study area. Thus, we recommend an integrated approach including mechanical, manual, biological, nutrient management and chemical methods following scientific procedures.
- ✓ Land use management along the rivers and in the catchment needs improvement so as to reduce nutrient loads that contribute to the proliferation of water hyacinth.

## **Chapter 6: Water Hyacinth Control and Management Strategy: The Prospects of Willingness to Contribute Household Labor**

### **Abstract**

*The dynamics of water hyacinth propagation make its management more challenging. Affordability, applicability, and effectiveness of the controlling mechanisms are uncertain across different regions. Labor-abundant countries prefer manual control mechanisms as compared to mechanical, chemical, or biological approaches. However, different demographic and economic factors impede control strategies. Thus, this paper aims to assess people's willingness to participate and contribute labor and evaluate the determinants. The study was done in the Central Rift Valley Lakes, Dembel and Koka, East Shewa Zone, Oromia Regional State, Ethiopia. A statistical procedure is adopted to select 400 samples. A structured questionnaire, managed by the Kobo toolbox, is used to collect data through face-to-face interviews. The result shows that 96 percent of the respondents are willing to participate. However, the willingness to contribute labor is affected by the initial and secondary bids, gender, lakes' water quality knowledge, livestock size, and completed education level. The mean willingness to contribute labor is 26.6 hr. per month. In monetary terms, its value is 900 ETB per month which is 3600 ETB per person per year. To ensure sustainable water hyacinth management, there should be sympathetic insights into the opportunities and substantially empower the local people to benefit from water hyacinth control projects.*

**Keywords:** Bid; Contingent Valuation; Dembel; Koka; Seemingly Unrelated Bivariate Probit

## 6.1 Introduction

Water hyacinth is one of the world's most invasive aquatic plants, which is native to tropical and subtropical South America, then has been spread around the world (European and Mediterranean Plant Protection Organization, 2008; Navarro and George, 2000; Pan et al., 2012). This species has recently posed considerable impacts on the environment, humans, and economic activities. From the human health perspective, it transmits disease (Harun et al., 2021) by creating a conducive environment for the reproduction of the vector (Maulidyna et al., 2021), bacteria (Wang, 2021), and other waterborne diseases (Corman et al., 2023). Similarly, it facilitates the expansion of mosquitoes (Chapungu et al., 2018) which supports malaria transmission (Getahun and Kefale, 2023; Gezie et al., 2018). Moreover, it causes a skin allergy (Enyew et al., 2020b), harbor bilharzia (PD20), and several other human and animal diseases (Getahun and Kefale, 2023; Ingwani et al., 2010).

Several studies have shown that water hyacinth distresses the aquatic ecosystem and its services. The water hyacinth-dominated environment promotes lethal gas production (Tewabe et al., 2017), methane emission (Oliveira Junior et al., 2021; Oliveira-Junior et al., 2017), and a reduction in dissolved oxygen (Getahun & Kefale, 2023). Similarly, recreational and cultural services like boating sails (Ingwani et al., 2010; Villamagna and Murphy, 2010) and aesthetic value (Dersseh, et al., 2019). Many of the aquatic ecosystems are disturbed by the weed. It also restricts the natural aesthetic of the river flow, swimming, as well as religious activity (Chapungu et al., 2018). This weed also affects the nutrient cycle (Ingwani et al., 2010) and primary production (Getahun and Kefale, 2023; Tewabe et al., 2017; Waithaka, 2013) capacity of the aquatic ecosystem to support services.

The economic impact of water hyacinth is mostly related to crop production, fish harvesting, and the cost of weed removal and ditch maintenance. In agrarian countries, it affects crop production (Damtie et al., 2021; Enyew et al., 2020c) restricts irrigation water flow (Getahun and Kefale, 2023) and limits production (Enyew et al., 2020b). This weed also reduces the amount of caught fish and the supply (Enyew et al., 2020d; Kateregga and Sterner, 2009; Tewabe et al., 2017) and prolong the harvesting rate (Damtie et al., 2021; Dersseh, et al., 2019b; Hussien et al., 2020). This water hyacinth-dominated environment can disturb seed germination (Mathur and Mathur, 2018), and apparently erode aquatic plant genetic resources (Churko, et al., 2023; Getnet et al., 2021; Tewabe et al., 2017).

As a result, it touches the livelihood of farmers and traders associated with the fish business (Ezama, 2019; Ogunlade, 2002; Segbefia et al., 2019). Equally, this invasive weed invites additional costs of management and maintenance. For instance, the high cost of weed removal from farmland (Damtie et al., 2021; Getahun and Kefale, 2023) and the maintenance cost of blocked ditches and canals (Dersseh et

al.,2019; Hill, 2003) are among others. In sum, it will cost a lot unless an appropriate controlling system is implemented.

One of the challenges to control water hyacinth is its diverse propagation method. Sexually, water hyacinth reproduces a large number of seeds that can live for many years in the natural seed banks (European and Mediterranean Plant Protection Organization, 2008). Asexually, it can be multiplied by budding and by asexual production (Sharma and Aggarwal, 2020). In addition, the water hyacinth is naturally dispersed by running water and floodwater (Pan et al., 2012; Zhang and Guo, 2017) and human intervention (European and Mediterranean Plant Protection Organization, 2008).

Several efforts have been made globally to control and manage water hyacinth. Though the effectiveness and affordability of water hyacinth controlling methods remain uncertain, the most common mechanisms are manual, mechanical, chemical, and biological (Hill and Coetzee, 2008). The manual removal mechanism has been considered a feasible way to control/manage the weed in labor-abundant developing countries (Dechassa and Abate, 2020). Yet, few studies have been conducted in and around Lake Dembel. For instance, economic value and people's perceptions of the Lake Dembel ecosystem services (Desta, 2021; Desta, 2018), and willingness to restore Lake Dembel water water-based ecosystem services (Girma et al., 2021).

Most of the studies related to water hyacinth have been conducted in Lake Tana, Ethiopia. Most of the papers have focused on the willingness to pay for water hyacinth control (Ebrahim et al., 2023; Tasew, 2019), farmers' preference for water hyacinth control (Van Oijstaeijen et al., 2020), and participatory weed management (Sewunet, Girma, et al., 2022). Several water hyacinth-related studies are also conducted in different parts of Ethiopia and mostly are focused on the effect (Hussien et al., 2020; Tewabe et al., 2017), perception (Enyew et al., 2020e), infestation potential (Minychl G et al., 2019), ecological, economic, and social implications (Getahun and Kefale, 2023), and its impact (Damtie et al., 2022). Some studies assessed the socioeconomic and environmental sustainability (Churko et al., 2023), water quality (Getnet et al., 2021), and its impact on aquatic life and human activities (Ingwani et al., 2010).

However, studies that address the willingness to contribute labor for water hyacinth management in Dembel and Koka Lakes are limited. So, this study aimed to assess people's willingness to participate in water hyacinth control/ management in the study area. Specifically, the study focused on households' modality preference to control water hyacinth, their willingness to contribute labor, and factors that impede the willingness to control this invasive weed, and to evaluate the mean willingness to contribute labor per household per year. We hypothesized that the household's wealth and education level are likely to affect their participation and contribution towards water hyacinth control/management.

## 6.2 Methodology

### Sampling procedures

This study was implemented in three districts, Lume, Dugda, and Adami Tulu Jido Kombolcha in the East Shewa Zones of the Oromia Regional State. The districts were selected for their proximity to Lake Dembel and Koka. The Zone and the districts were purposely selected because of the water hyacinth infestation along the edge of the two lakes. The study kebeles were randomly selected from those kebeles with water hyacinth. In this case, lists of Kebeles with high water and no water hyacinth infestation were prepared through discussion with experts working on water hyacinth management in Lume, Dugda and Adami Tulu Jido Kombolcha districts. Furthermore, the study kebekes/sites were verified by field visits to the area. From the list, six Kebeles were selected from Lume, six from Dugda, and four from Adami Tulu Jido Kombolcha. Based on the proximity of individual households, the respondents were grouped as adjacent and not adjacent to water hyacinth invaded lakes within the kebele. The total sample size of households was determined based on equation 5.1.

Based on the data obtained from the Environmental Protection and Agricultural Development offices of the districts, the total number of households in the selected kebeles were 8654. Accordingly, the sample size is equal to 382, considering the probability that some of the respondents might not be available for an interview or refuse to be interviewed, 5% of the sample (18) households were added to make the total 400 samples. The proportionate sampling technique was employed to determine the sample size from each kebele (Table 14).

Table 14. Sample size distribution in the districts and kebeles

Kebeles	Districts			Total
	Lume	Dugda	Adamitulu Jidu Kombolcha	
Abine Garuma	0	0	21	21
Abo Gabriel	0	20	0	20
Adada Dambel	39	0	0	39
Bakale Girisa	0	20	0	20
Batu 2	0	0	20	20
Batu Town	0	0	8	8
Bochesa	0	0	21	21
Bochesa 2	0	0	19	19
Darara Dambel	39	0	0	39
Dodota Dembel	0	20	0	20
Dugugi Bakele	39	0	0	39
Garba Korke Adi	0	20	0	20
Ido Gojola	0	0	16	16
Qoqa Nagao	39	0	0	39
Tepho Choreke	0	19	0	19
Tuchi Dembel	0	20	0	20
Wayo Gabriel	0	20	0	20
Total	156	139	105	400

## **Data type and collection**

The type of data considered in this paper is fully quantitative cross-section data collected from households using a structured questionnaire. The questionnaire was managed and collected by the Kobo toolbox. One supervisor and four data collectors were recruited, and training was given. The data was collected through face-to-face interviews from May 12 to June 15, 2024.

## **Method of data analysis**

Descriptive statistics is employed to address households' willingness to contribute labor (WTCL). Statistical software's, SPSS and STATA, were used to encode and analyse the data, respectively. SPSS is compatible with the Kobo toolbox to import data and clean, while STATA was used to analyze descriptive statistics and econometric models. Descriptive analysis was used to compare demographic and socioeconomic variables grouped by the offers. The results are described by mean, frequency, and percentage. To validate the result, inferential statistics such as t-test and chi-square were applied.

## **Contingent Valuation Method**

Contingent Valuation (CV) is a stated preference technique used to value non-marketable public goods (Prato, 1998). Even though there are gaps in different approaches for WTP questions, the double-bounded dichotomous is statistically more efficient than single single-bounded choice (Timothy C. Haab and Kenneth E. McConnell, 2002). Hence, those WTCL in the control of water hyacinth presented with the initial bids, which were identified during the preliminary survey. The labor contribution modality of the choice model was set based on the preference of sample respondents in the study area. The following scenario was briefed for respondents in the preliminary as well as during the sample survey.

'You are well aware of the effect of water hyacinth on social, economic, and the environmental as compared to the lake situation some years back. So, removing the weed is expected to benefit you through the improvement of the Lakes' ecosystem goods and services. Hence; if there would be a project working on the removal of the weed, yet it would require the participation of the community. The community participation is substantial until the weed is permanently removed from the lake.' After describing the scenario, the preliminary survey samples were asked to choose a modality in the following open-ended questions

1. Are you willing to participate in such activity?  
\_\_\_\_\_
2. If you are willing to participate, in what modality? A) In-kind (providing labor) B) in cash (C) Other (specify)  
\_\_\_\_\_

3. If in kind; the time you would likely to work per month (in hours)

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4. If in cash, the amount of money you are willing to contribute in birr per month

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The result shows that all the respondents preferred to contribute labor. Hence, the contingent valuation modality was developed accordingly to address their interest.

### **Contingent valuation with dichotomous choice questions**

To analyze the determinants of WTCL, either seemingly unrelated bivariate probit or double bounded model can be used. Respondents were asked two questions whether they are willing to contribute labor to control water hyacinth in the Lakes or not. Their answer to the first question is either yes (if they are willing to contribute labor for the initial bid amount ( $IB_i=1$ )) or no (if they are not willing ( $IB_i=0$ )). Following the first answer, they are also asked to answer the second question (secondary upper bid, if the response for  $IB_i=1$  or secondary lower bid, if the response for  $IB_i=0$ ). Their answer to  $SB_i$  is either yes (if they are willing to contribute labor for the secondary bid amount ( $SB_i=1$ )) or no (if they are not willing ( $SB_i=0$ )). In this regard, the dichotomous choice model provides more information as compared to one question (Lopez-Feldman, 2012). Therefore, the CV with dichotomous choice questions is addressed by using seemingly unrelated bivariate probit model as follows.

$$WTCL_i(X_i, U_i) = \alpha_0 + X_i\beta + U_i \text{ And } U_i \sim (0, \sigma^2) \quad 6.1$$

Where  $WTCL_i$  is the willingness to contribute labor,  $\alpha_0$  is a constant parameter,  $X_i$  is a vector of explanatory variables (Table 1 of Annex 1),  $\beta_i$  is a vector of parameters,  $U_i$  is an error term, and  $U_i \sim (0, \sigma^2)$  is the normality distribution of the  $U_i$  assumption with zero mean and constant variance.

So, there are four possible responses expected from the dichotomous choice questions. Accordingly, the  $IB_i$  and  $SB_i$  answer might be yes to the first question and no for the second (1, 0), yes to both questions (1, 1), no to the first question and yes for the second (0, 1), or no to both question (0, 0). Therefore, the probabilities are expressed as:

$$Pr (IB_i=1, SB_i=1) = Pr (1, 1) = Pr (WTCL_i > IB_i, WTCL_i \geq SB_i)$$

$$Pr (IB_i=1, SB_i=0) = Pr (1, 0) = Pr (IB_i \leq WTCL_i < SB_i)$$

$$Pr (IB_i=0, SB_i=1) = Pr (0, 1) = Pr (SB_i \leq WTCL_i < IB_i)$$

$$Pr (IB_i=0, SB_i=0) = Pr (0, 0) = Pr (WTCL_i < IB_i \leq SB_i)$$

These expressions can be explained in more advanced terms of the probabilities associated with the threshold of a standard bivariate normal distribution. Refer to Cameron and Quiggin (1994) and Lopez-Feldman (2012) for the detail and the log-likelihood function of this model.

### The mean willingness to contribute labor

The mean willingness to contribute labor in a single bounded bivariate probit model is found by first estimating the WTCL and then simply computing the mean WTCL manually which is the ratio of constant parameter ‘ $\alpha$ ’ to the bid parameter ‘ $\beta$ ’ (Eq. 6.2) (Woldemedhin et al., 2021). In case of double bounded model with and without control variable, the mean willingness to contribute labor is analyzed by using doubled command in STAT and nonlinear combinations of parameter estimates after estimating the WTCL (Lopez-Feldman, 2012).

$$WTCL_i = \alpha + \beta Bid_i + U; \text{ Mean WTCL} = - (\alpha / \beta) \quad 6.2$$

Table 15. Variable description included in this study

Variable Name	Description	Type of variable
WTCL	Dependent variable which is defined as the willingness to contribute labor in hour per month	= 1 if the answer to the IB and SB are yes, yes; 0 otherwise = 1 if the answer to the IB and SB are yes, no ; 0 otherwise = 1 if the answer to the IB and SB are no, yes; 0 otherwise
IB	The initial amount of labor in hour per month (initial bid); predetermined in preliminary survey	= 4, 6, 8, and 12
SB	The second upper or lower amount of labor in hour per month (secondary bid); following the response to IB	= 2; 3; 4; 6; 9; 12; and 18
SEX	Biological character of the respondent	= 1 if the respondent is male; 0 otherwise
Education	The education status of the respondent	A continuous variable measured in completed year
Land	The amount of land owned by the household	A continuous variable measured in hectare
Water deterioration	Perception of the respondent about observed water deterioration in the Lakes due to water hyacinth	= 1 if observed; 0 otherwise
TLU	Unit of livestock owned by the household	A continuous variable measured in Tropical Livestock Unit (TLU)
On-farm income	The amount of return obtained in agricultural activities (from crop, vegetable, and fruit)	A continuous variable measured in Ethiopian currency, BIRR
Adjacent to Lakes		= 1 if the respondent location is up to 300m far from lakes; 0 otherwise

## 6.3 Results

### Respondents' willingness to participate in water hyacinth control

The respondents' willingness to participate in water hyacinth control is asked prior to addressing the bid questions. Approximately 96 percent of the respondents in three districts are willing to participate. As shown in Table 16, the reasons of those respondents who are not willing to participate (5%) are due to old age unable to afford labor, considering it is the role of government, do not want to incur costs, and due to job overlapping in daily duty to contribute labor.

Table 16. Willingness to participate and contribute labor control water hyacinth

Willing to participate	Districts			
	Lume	Dugda	Adamitulu	Total
Initial bid				
4	17	38	38	93
6	19	39	39	97
8	20	38	38	96
12	44	19	33	96
Total	100	134	148	382
Not willing to contribute (4.5%)	Reason for not willing to contribute labor			frequency
	Due to old age			13
	Consider it as the Government role			3
	It costs			1
	Job overlapping			1
Total				18

Among the respondents willing to participate, approximately 83 percent are willing to contribute labor (WTCL) for the initial bid level. Among these, 94 percent of the respondents are willing to contribute a 4-hour labor per month as compared to other initial bid levels. The minimum proportion of respondents to contribute labor is found in the initial bid level of 8hr per month. About 87 and 79 percent of the respondents are willing to contribute initial bid level 6-hr and 12-hr, respectively. The chi-square results in Table 6 of Annex 1 show there is a significant difference among respondents and within the initial bid levels.

Similarly, following the answers of respondents for the initial bid, secondary bid was asked. Both respondents willing and not for the IB were asked secondary bid level. Accordingly, a higher SB is asked for those responded yes in the IB, while lower SB level for no answer (not willing to the IB level). Thus, 99 percent of the respondents are willing to contribute labor for the SB level. The chi-square result shows there is no significant difference among respondents and within secondary bid levels (Table 17).

Table 17. Willingness to contribute labor in hours per month

Labor	Initial bid (IB)			Secondary bid (SB)		
	No	Yes	Total	No	Yes	Total
2	-	-	-	0	6	6
3	-	-	-	0	13	13
4	6	87	93	1	24	25
6	13	84	97	3	104	107
8	25	71	96	-	-	-
9	-	-	-	0	84	84
12	20	76	96	0	71	71
18	-	-	-	0	76	76
Total	64	318	382	4	378	382
Pearson		14.94			7.9358	
Prob.		0.0019			0.243	

### Household characteristics and their labor contribution

Respondents' willingness to contribute labor to control water hyacinth invasion were categorized based on sex, marital status, involvement in on-farm activities, and dependency on the Lakes. Accordingly, about 78 percent of female and 85 percent of male households are willing to the IB. Though there were similarities between sex and marital status for the IB, there was significant variation in the willingness response to contribute labor for SB (Table 18).

Of the total respondents, about 60 percent are engaged in on-farm activities and 99 percent of them are willing to the initial bid while the total respondents who are not engaged in on-farm activities, 47 percent are willing to the IB. The chi-square result shows there is a significant difference between these households on the WTCL. This means water hyacinth has more claimed by those engaged in on-farm activities as compared to the others. Likewise, the on-farm activities whose livelihood depends on the Lakes (86%) are more than those do not dependent on it (14%). Yet, all of the households that do not depend on the Lakes (100%) are willing to the IB as compared to those that depend on the Lakes (81%). The chi-square result also shows a significant difference in the willingness to contribute labor between household's dependencies on the Lakes.

Table 18. Household characteristics and WTCL for water hyacinth control

Variables (n=382)	Category	Willing to provide labor		Prob.	Willing to provide labor		Prob.
		No (n=64)	Yes		No (n=64)	Yes	
Sex	Female	17	61	0.1814	3	75	0.0065
	Male	47	257		1	303	
	Married	47	259		3	303	
Marital Status	Single	1	10	0.2477	1	10	0.0558
	Divorced	2	4		0	6	

	Widow	14	45		0	59	
<b>On-farm activities</b>	No	60	54	0.000	0	114	0.1898
	Yes	4	264		4	264	
<b>Dependent on Lakes</b>	No	0	53	0.0004	0	53	0.4197
	Yes	64	265		4	325	

As shown in Table 19, TLU shows a significant mean difference of 0.84 units. It means respondents who are willing to contribute the IB have more livestock size than not willing households. Similarly, there is a significant difference between respondents' dependency ratio and land holdings. The dependency ratio for those not willing to contribute SB is higher by 0.848. Regarding land ownership, the mean land size of those households' willing to contribute labor for the SB is higher by 1.147 ha. There is insignificant mean difference in age, education, family size, total incomes and incomes from on-farm, off-farm, and fish. The negative mean indicates that the value of demographic and socio-economic variables for the households not willing to contribute labor is higher than the other (Table 19).

Table 19. Household demographic & socio-economic characteristics & willingness to contribute (IB)

household characteristics	IB		SB	
	Mean Difference	t-value	Mean Difference	t-value
Age	1.078	(0.57)	-13.12	(-1.91)
Education	0.781	(1.95)	-0.638	(-0.43)
Total number of family Size	0.517	(1.89)	-1.665	(-1.66)
Household dependency ratio	-0.0454	(-0.40)	-0.848*	(-2.04)
Land size, ha	-0.0350	(-0.25)	1.147*	(2.35)
<b>Economic characteristics</b>				
On-farm Income	-3943.7	(-0.85)	-15684.7	(-0.92)
Off-farm Income	5713.6	(1.62)	-8797.0	(-0.68)
TLU	0.837*	(2.31)	0.835	(0.62)
Fish Income	-145659.0	(-0.44)	-135356.4	(-0.11)
Total Income	-143889.0	(-0.43)	-159838.1	(-0.13)

t statistics in parentheses

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

### Household knowledge of water hyacinth and their willingness to contribute labor

Households in the study area are directly or indirectly associated with the Lakes. On the one hand, although 49 percent of the total respondents are adjacent to the invaded Lakes, approximately 81 percent of them are willing to provide labor to control water hyacinth. On the other hand, though 51 percent of the respondents are far from the invaded Lakes, approximately 86 percent of them are willing to contribute labor. Yet, there is no significant difference within households' proximity to the invaded Lakes and their willingness to contribute labor (Table 20).

Regarding water hyacinth control measures in their locality, most of them (58.6%) know the activity that has been done. Accordingly, 73 percent of the respondents who know the control measures and 99 percent who do not know are willing to contribute labor. The chi-square result shows a significant difference between respondents' knowledge and their willingness to contribute labor. Those households that do not have knowledge about water hyacinth control measures are more willing as compared to the others.

Few respondents (11%) perceived disease due to water hyacinth infestation, while most of them (89%) do not know diseases related to it. Approximately 85 percent of respondents do not perceive disease due to water hyacinth and 93 percent that know the disease related to the weed are willing to contribute labor. The chi-square result reveals a significant variation between respondents' knowledge and their willingness to IB and SB regarding water hyacinth control measures in their locality and water hyacinth related disease.

Table 20. Households' knowledge about water hyacinth in terms of their willingness to pay

Respondents' category (n=382)	Res	WTCL IB			WTCL SB		
		No	Yes (n=318)	Prob.	No	Yes	Prob.
Adjacent to invaded Lakes	No	28	166	0.2172	1	193	0.2997
Knowledge of WH control measures	Yes	36	152	0.0000	3	185	0.0988
	No	2	149		0	151	
Perceive disease due to WH	Yes	61	163	0.0684	4	220	0.0001
	No	61	278		1	338	
	Yes	3	40		3	40	

### **Determinants of households' participation and the mean willingness to contribute labor**

The above descriptive result explains variation in the willingness to contribute labor among households based on demographic and socio-economic characteristics. Yet these results do not reveal the extent and direction of their influence. In this regard, seemingly unrelated bivariate probit model is used to quantify factors that determine the willingness to participate by contributing labor for water hyacinth control (table 6 of Annex 1).

The result shows that the willingness to contribute labor (WTCL) is affected by the initial and secondary bids, sex of the respondent, knowledge about lake water deterioration due to water hyacinth, livestock size, and educational status of the respondent. Hence, as the initial and secondary bids increase, the WTCL declines. Similarly, male respondents are more willing to contribute labor as compared to female counterparts. In contrast, respondents with knowledge of Lake water quality deterioration, their WTCL declines as compared to those who do not have the knowledge. Likewise, as the livestock size and completed education level of the households increase their WTCL declines.

Table 21 shows the marginal effect result after bivariate probit model. Accordingly, as the initial bid increases by one level, the households' willingness decreases approximately by 1.3 percent. Similarly, being male, the WTCL increases by 24 percent as compared to female respondents.

Having the knowledge of water quality deterioration due to water hyacinth, respondents' WTCL decline approximately by 8 percent compared to those who do not know the case. Likewise, an increase in the livestock size by one TLU and education level by one year of schooling, the respondents' WTCL increases approximately by 2 and 1 percent, respectively.

Table 21. Marginal effect of households' willingness to participate in WH control

y = Pr. (IB Are you WTCL =1, SB Are you WTCL=1) (predict) = .86471101							
Variables	dy/dx	Std. Err	Z	P>z	[ 95% C.I. ]	X	
IB	-0.013	0.006	-1.98	0.048	-0.025	-0.00	7.515
Sex*	0.124	0.059	2.10	0.036	0.008	0.24	0.791
Education	-0.010	0.006	-1.71	0.086	-0.02	0.001	2.094
Land	0.003	0.020	0.14	0.891	-0.037	0.04	1.368
Water	-0.075	0.019	-3.88	0.000	-0.113	-0.04	2.477
TLU	-0.015	0.007	-2.27	0.023	-0.028	-0.002	3.027
On-farm	0.000	0.000	0.29	0.775	-0.000	0.000	19716.7
SB	0	0	.	.	0	0	9.904

(\*) dy/dx is for discrete change of dummy variable from 0 to 1

### Mean willingness to contribute labor

The mean willingness to contribute labor is computed using three model results. The first model considers only the bids without including control variables. Accordingly, the mean WTCL is simply constant and is 22.8 hr per month. The second model is single-bounded, considered only the initial bid and control variables. As a result, the mean WTCL is 26.6 hr per month. The third model is double-bounded, considered both the initial and secondary bids together with the control variables. In this case the mean WTCL is negative 1.53 hr. per month (Table 22).

The average labor cost (wage) per day in the study areas during the survey was conducted by 300 ETB and 26.6 hours is estimated to 3 work-days per month. In this regard, the monetary value of water hyacinth control is 900 ETB per month in a single bounded willingness to pay considering control variables. Assuming that one HH can contribute 4 month per year, annual mean WTP will be 3600 ETB per person. Though approximately 96 percent of the households in the three districts are willing to contribute labor for the water hyacinth project, it will bring substantial progress in the invasive weed reduction on the lakes of the Central Rift Valley. Thus, if only selected kebeles' are considered, there

will be 8,308 household heads that are willing to contribute labor, which is approximately 29,908,800 ETB per year for water hyacinth management.

Table 22. The mean willingness to contribute labor

Model	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
Double-bounded with no control variables						
Beta_cons	22.835	1.571	14.54	0.000	19.756	25.914
Sigma_cons	11.412	1.198	9.520	0.000	9.064	13.761
With control variable						
Double bounded	-1.5289	0.245492	-6.23	0.000	-2.01003	-1.04772
Single bounded	26.579	9.61661	2.76	0.006	7.73140	45.4278

## 6.4 Discussion

Water hyacinth invasion exerts a serious challenge on smallholder farmers activities in developing countries (Honlah et al., 2019). Although there are several mechanisms to control water hyacinth (Dechassa and Abate, 2020) most of them are not affordable to rural households (Wyk and Wilgen, 2002). So, developing countries have to use local labor resources to manage the dynamic expansion the weed (Dechassa and Abate, 2020). In this regard, this paper looked at the households' willingness to contribute labor to manage and control this invasive aquatic plant.

Though labor is abundant in rural areas, its demand and supply widely vary according to seasonality in agricultural activities. During labor-intensive seasons, labor supply influences the community based voluntary activities (Defrancesco et al., 2008). In this respect, in agreement with Ebrahim et al. (2023), households are less willing to contribute labor for higher bids.

Gender disaggregated labor division is common in rural households pertinent to on-farm and off-farm activities (Terefe et al., 2023). There are several determinants of labor distribution between males and females (Do et al., 2020). Similarly, there are different theories for gender disaggregated labor division (Coltrane, 2010). Thus, it is clear that females have additional social and biological influence (Witt, 1994), most of the time laborious works are done by males as compared to females. So in the findings, the WTCL, since it is troublesome to remove the weed from the lake, male households are more involved as compared to females. Similarly, as the educational status of the respondents increases, their attitude to contribute labor voluntarily for environmental problems decreases, particularly for arduous activities (Yuan et al., 2017). Conversely, educated households are more willing to contribute money than labor in such projects (Sewunet et al., 2022).

On the one hand, knowledge about the negative consequence of water hyacinth on the quality of water bodies associated with water-born and other diseases, limits volunteers to contribute labor fearing its

health impact (Dechassa and Abate, 2020). On the other hand, the low cost of labor increases the interest of households to participate in environmental activities (Meng et al., 2022) in terms of money contribution. Thus, households with high incomes are highly willing to pay (Van et al., 2020) rather than to contribute labor. Likewise, households who have better economic status are willing to participate voluntarily in pro-environmental activities (Boz, 2017).

Livestock size is an indicator of the household wealth in the rural community (Nkedianye et al., 2019). In this regard, households that have more livestock in TLU are less WTCL. Several explanations can be mentioned for their decision; first, these households have shown an interest in participating in the water hyacinth controlling project. Yet, they may not feel comfortable contributing labor together with other respondents of the lower economic group rather they might prefer to contribute in cash. Second, if their feed sources are not related to the communal grazing wetland infested by water hyacinth, they might not bother about the issue, so their WTCL would likely decline. Last, if this invasive weed is used as livestock feed, those respondents who have larger livestock sizes may not have an interest in controlling the water hyacinth. Hence, they may not show an interest in contributing to labor.

## **6.5 Conclusion and Recommendations**

The result presented in this paper addresses households' willingness to participate in water hyacinth control projects proposed in the Ethiopian Central Rift Valley Lakes. The contribution of labor is not the only modality to be considered as a strategy in the management of this invasive weed. Though labor is an abundant resource, other factors that affect its contributions need to be considered. In this respect, age, sex, education, and wealth level of the society should be considered to address their preference modality. The current study found that in addition to labor contribution, any project proposed in the study area should allow another alternative such as hiring labor, donating machinery, providing chemicals, and other resources suggested in the water hyacinth controlling scheme.

Furthermore, to ensure sustainable water hyacinth management in the long run, it would be better to consider the law of "matter neither created nor destroyed, but it transformed from one form to another". Thus, a sympathetic look at opportunities should be part of the project. In this regard, it would be crucial to provide training and awareness to local people on how to utilize the weed for several purposes through benchmarking the best lessons from other countries.

# **Chapter 7: Water Hyacinth Management and Policy Implications in the Central Rift Valley of Ethiopia: Stakeholders, Institutions and Community Engagement**

## **Abstract**

*The pervasive challenge of managing the invasive aquatic plant, water hyacinth (Eichhornia crassipes), poses significant ecological and socio-economic threats in Ethiopia. This study delves into the complexities of water hyacinth management by examining institutional frameworks, policy effectiveness, community involvement, and resource allocation strategies. Through interviews with 24 key informants from diverse organizations, including government bodies, NGOs, and international institutions, the research provides a nuanced understanding of the challenges and prospects in managing this invasive species. Ethiopia's strategic approach to water hyacinth management is underpinned by a series of policies and regulatory frameworks aimed at environmental conservation and sustainable resource management. The National Water Policy, for instance, emphasizes integrated water resource management and recognizes the critical need to control invasive species to protect aquatic ecosystems. Environmental Protection Laws further mandate the assessment of environmental impacts caused by such invasions and necessitate the involvement of local communities in management efforts. Despite these comprehensive policies, the study reveals that the practical implementation of these regulations is fraught with challenges. The effectiveness of existing policies varies significantly, largely due to resource constraints, insufficient integration of policy measures, and a lack of robust enforcement mechanisms. Informants noted that while frameworks exist, their execution is often hindered by bureaucratic delays, limited inter-agency collaboration, and fragmented responsibilities among stakeholders. Additionally, the disconnect between policy formulation and on-the-ground implementation remains a significant barrier, with many communities unaware of their roles and responsibilities within these frameworks. Community involvement emerges as a pivotal factor in successful water hyacinth management. The research highlights instances where empowered communities, supported by clear policies and technical training, have actively engaged in management activities. However, such successes are not widespread, pointing to a need for improved communication, education initiatives, and participatory forums that allow communities to contribute meaningfully to policy formulation. The study also underscores the fragmented approach to managing water hyacinth, with varying levels of engagement from stakeholders. Government bodies, NGOs, and international organizations are involved, yet their efforts are often uncoordinated, reducing the overall impact of management strategies. Informants recommended the establishment of centralized task forces to streamline efforts and enhance resource allocation, ensuring a cohesive and*

*sustained response to water hyacinth infestations. Furthermore, the study examines the management techniques employed in Ethiopia, noting that traditional methods such as manual removal have not yielded significant results. The need for an integrated approach, incorporating biological control and nutrient management, is emphasized as a more sustainable solution. By reducing nutrient influx into water bodies, conditions favorable for water hyacinth growth can be mitigated, thereby addressing the root causes of infestation. In conclusion, the study highlights the need for a robust policy framework that not only provides clear guidelines but also ensures practical implementation and community involvement. By addressing existing gaps and enhancing regulatory mechanisms, Ethiopia can create a more effective and sustainable approach to managing water hyacinth. Collaborative efforts between government, NGOs, local government, private sectors and local communities are essential for achieving long-term success in combating this invasive species. The research calls for a shift towards integrated management strategies that consider ecological, social, and economic dimensions, fostering resilience and sustainability in Ethiopia's water resource management.*

**Key words:** Invasive species, Institute, Community participation, Policy, Combating water hyacinth

## 7.1 Introduction

Management of invasive species is crucial due to their profound impacts on biodiversity, ecosystems, and economies. Invasive species can lead to the extinction of native flora and fauna, alter habitats, and disrupt ecosystem functions (Abba et al., n.d.). Water hyacinth, in particular, is notorious for obstructing waterways, impacting aquatic life, and creating breeding grounds for disease vectors (Djihouessi et al., 2023). Globally, sustainable management of water hyacinth is necessary to mitigate its environmental and economic impacts. The plant's rapid growth can lead to severe ecological disturbances, demanding effective management strategies that are both environmentally friendly and economically viable (Djihouessi et al., 2023). Sustainable approaches are needed to convert this invasive weed into valuable resources, reducing its negative footprint (He X et al, 2022). Conventional management often involves mechanical and chemical methods, which are costly and can harm the environment. Sustainable management emphasizes biological control and resource utilization, offering a more balanced approach that aligns with ecological and economic goals (He X et al, 2022). Stakeholders, including local communities, NGOs, and government bodies, play a pivotal role in the management process. Their participation ensures a comprehensive approach that incorporates diverse insights and resources. Effective stakeholder engagement is linked to the success of management programs (Zikargae, 2022). Integrating policy frameworks with stakeholders and institutions is vital to sustainable management. Policy development should be inclusive, involving all relevant actors to ensure that management strategies are aligned with local and national priorities (Djihouessi et al., 2023).

The nexus of policy, institutions, and stakeholders creates a collaborative environment that is essential for effective management. This integration allows for shared responsibilities and resources, promoting innovative solutions and adaptive management practices (Sianipar, 2023). Research is needed to explore management practices that consider policy, institutions, and stakeholders. Such studies can provide insights into effective strategies and highlight areas for improvement, fostering better management outcomes (Lemke & Harris-Wai,2015). The research on sustainable water hyacinth management aims to develop strategies that leverage policy, institutional frameworks, and stakeholder engagement to achieve ecological balance and economic benefits. It seeks to transform the challenges posed by water hyacinth into opportunities for sustainable development (Jha et al, 2014)

Water hyacinth management generally involves a combination of physical, chemical, and biological methods. Physical methods include manual removal and mechanical harvesting. Chemical methods use herbicides like glyphosate, while biological methods introduce natural predators such as specific insects to control the plant population (Texas A&M AgriLife Extension, n.d; FAO, nd). The management of water hyacinth can be classified into mechanical, chemical, and biological forms. Mechanical control

involves machines to remove the plants, while chemical control applies herbicides to suppress growth. Biological control uses natural enemies like insects to reduce the plant's spread (Lake Forest College, n.d. ;Djihouessi et al 2023).

The management process involves identifying the infestation area, selecting appropriate control methods, and implementing these methods. Each method has specific components, such as herbicide application techniques or biological agent release (De Carvalho, 2019). Control aims to reduce the plant's impact, while eradication seeks to completely remove it from the area (Harley, 1990). Implementation involves integrating various control methods for maximum efficiency. It requires collaboration between stakeholders, continuous monitoring, and adjustment of strategies based on effectiveness. Successful implementation often uses an integrated management plan that combines mechanical, chemical, and biological controls (Djihouessi et al., 2023). Sustainable management ensures long-term control and involves using eco-friendly methods that minimize environmental impact. Strategies include using biological control agents that do not harm native species and implementing practices that reduce nutrient loads in water bodies, which fuel hyacinth growth (S.H. Yan et al., 2017).

Global policies for managing water hyacinth often focus on environmental mitigation and the control of its spread. These policies typically designate water hyacinth as a noxious weed, necessitating coordinated management efforts across borders (UNEP, n.d). Strategies include converting water hyacinth biomass into biofuels and other products, recognizing its potential for environmental and economic benefits (Nega et al., 2024). Policy trends have evolved to incorporate more integrated and adaptive management strategies. Spatially, regions like Africa have been focusing on joint monitoring and management initiatives to tackle the spread across shared water bodies (Mqingwana et al., 2024). Implementation approaches include mechanical, chemical, and biological control methods. Policies often advocate for reducing nutrient loads in water bodies to prevent proliferation and support sustainable, long-term control through biological methods (Djihouessi et al., 2023).

The effectiveness of global water hyacinth policies varies. Some regions have successfully leveraged biological control methods to reduce infestation levels significantly, leading to economic benefits such as increased agricultural productivity (UNEP, n.d). However, challenges remain, particularly in areas lacking resources and coordinated efforts (Djihouessi et al., 2023). Key barriers include bureaucratic delays, lack of coordination among institutions, and inconsistent regulatory frameworks across regions. These issues hinder the swift initiation and implementation of effective management programs (National Invasive Species Council. (n.d.). Africa presents significant opportunities for innovative policy implementation. Initiatives such as local community involvement in harvesting water hyacinth for economic gain and environmental mitigation are gaining traction. These efforts not only manage the weed

but also provide socio-economic benefits (Nega et al., 2021). Institutions play a crucial role by supporting policy development, facilitating stakeholder collaboration, and ensuring the enforcement of regulations. They are responsible for coordinating efforts among various stakeholders and providing the necessary resources for effective management (Honlah, 2022).

Institutions globally play a critical role in the management of water hyacinth by establishing frameworks that integrate ecological, economic, and social considerations. They often coordinate efforts among various stakeholders; provide technical expertise, and support research and development in control measures (Djihouessi et al., 2023). Institutionally, there has been a shift towards more integrated and collaborative approaches that emphasize sustainable management. Over time, institutions have moved from isolated control efforts to comprehensive programs that involve community participation and international cooperation (Honlah, 2022). Implementation frameworks often include legal, regulatory, and policy components that guide actions at both national and international levels. These frameworks are supported by strategic planning, coordination between government bodies, and partnerships with non-governmental organizations (OECD.n.d.) The effectiveness of these frameworks varies globally. Successful implementation often hinges on the adaptability of policies to local conditions, availability of resources, and active participation of local communities. In many cases, integrated strategies that combine biological, chemical, and mechanical control methods have shown promise (Djihouessi et al., 2023). Major barriers include bureaucratic delays, lack of funding, inconsistent policies, and inadequate stakeholder engagement. Institutional rigidity can hinder the adoption of innovative solutions, and there is often a need for more dynamic and responsive frameworks (Wang, 2009). Africa presents opportunities for leveraging institutional frameworks to turn water hyacinth challenges into economic opportunities. Programs that focus on harvesting water hyacinth for biofuel production and other uses can provide economic benefits and improve livelihoods (Nega et al., 2021). Stakeholders, including local communities, government agencies, and NGOs, play vital roles in the implementation of institutional frameworks. Their involvement ensures that policies are well-informed, culturally appropriate, and effectively enforced. Stakeholders can provide local knowledge, resources, and support for educational and outreach programs (Zikarga, 2018).

Stakeholder participation refers to the involvement of diverse groups including local communities, government agencies, NGOs, and private sector entities in the management of water hyacinth. Effective participation is characterized by active engagement, shared decision-making, and collaborative action from planning through to evaluation (Anenberg et al., 2020). Participation can take various forms such as direct involvement in removal activities, financial support, policy advocacy, and educational outreach programs. Stakeholders may also engage in research and development initiatives to find sustainable

solutions (Zikargae, 2022). The stakeholder framework involves stakeholders from the inception of management plans through to their evaluation. This ensures that local knowledge is integrated, and management strategies are tailored to specific community needs and environmental conditions (Pratiwi et al, 2018). Effective stakeholder participation can lead to more sustainable and successful water hyacinth management. Evidence shows that when local communities are engaged, the control measures are more effective and have longer-lasting impacts (Nega et al., 2021). Barriers to effective stakeholder participation include lack of awareness, insufficient resources, and inadequate institutional support. These challenges can hinder collaboration and limit the effectiveness of management efforts (Potthoff et al, 2023). Globally, stakeholders in water hyacinth management include environmental agencies, research institutions, local governments, and international organizations. Each plays a role in policy formulation, funding, and execution of management strategies (Djihouessi et al., 2023). Over time, there has been a trend towards more inclusive and participatory approaches in water hyacinth management. Spatially, regions with significant infestations like Africa and Southeast Asia have seen increased stakeholder engagement in recent years (Zikargae, 2022). Stakeholder frameworks often involve mapping stakeholders, setting clear roles and responsibilities, and establishing communication channels to facilitate collaboration. This structured approach helps in aligning objectives and resources (Cochrane, 2023). The effectiveness of stakeholder frameworks is evident where there is sustained community engagement and clear coordination among stakeholders. Successful frameworks have led to reduced infestations and enhanced economic and ecological outcomes (Zikargae, 2022). Key constraints include institutional inertia, lack of funding, and resistance to change among stakeholders. Overcoming these barriers requires strategic leadership, capacity building, and continuous stakeholder education (Potthoff et al, 2023). Opportunities exist in leveraging stakeholder frameworks to enhance community participation, utilize water hyacinth as a resource, and integrate management efforts with broader environmental and economic goals (Nega et al., 2021).

In Africa, the synchronization of policy, stakeholders, and institutions is crucial for effective water hyacinth management. These elements must align to ensure coordinated action and resource allocation. Policies provide the legal and strategic framework, stakeholders offer local knowledge and resources, and institutions facilitate implementation and oversight (Zikargae, 2022) Policy formulation for water hyacinth management involves integrating environmental, economic, and social considerations. Factors affecting policy include political will, funding availability, stakeholder engagement, and scientific research. Policies must be adaptable to local conditions and responsive to emerging challenges (Djihouessi et al., 2023). Management practices are guided by policies that outline control methods such as mechanical removal, biological control, and chemical treatments. Effective policies promote integrated management approaches that are adaptive and scalable across different contexts (Karouach et al., 2022).

Community participation is essential for successful policy implementation. Policies should encourage community involvement in planning, executing, and monitoring management activities. This helps build local ownership and ensures that management strategies are culturally appropriate and sustainable (Zikargae, 2022).

Institutions play a key role in the execution of policies by providing governance, coordination, and technical support. They must work collaboratively with stakeholders to ensure that policies are effectively implemented and adjusted as necessary. Institutional frameworks should be flexible to accommodate different management needs (Djihouessi et al., 2023). The future of water hyacinth management in Africa depends on the continued alignment of policies, stakeholder participation, and institutional support. Emphasis on sustainable practices and innovative solutions, such as converting water hyacinth into biofuels, can offer economic and environmental benefits (Lubembe et al., 2023). Balancing the needs and interests of different stakeholders while ensuring effective management can be challenging. Tradeoffs may include prioritizing short-term economic gains over long-term ecological benefits or vice versa. Effective frameworks must navigate these tradeoffs to achieve sustainable outcomes (Navarro and Phiri 2000).

Ethiopian studies have explored various management practices for water hyacinth, including biological, mechanical, and chemical methods. The use of bioagents, like weevils, has been investigated for their effectiveness in controlling the plant in regions such as the Rift Valley (Gebregiorgis, 2017). Additionally, studies have assessed the impact of water hyacinth on local livelihoods around Lake Tana, highlighting the need for integrated management strategies (Damtie et al., 2021). While physical removal methods are commonly employed, they often prove ineffective in the long term. Research highlights the necessity for multi-year field studies to evaluate integrated management strategies under Ethiopian conditions (Dadhe et al, 2023). There is a significant gap in understanding the socio-economic impacts of water hyacinth management practices and their effectiveness in different ecological settings (Shebabaw, 2020). Ethiopian literature emphasizes the need for comprehensive policy frameworks to manage water hyacinth effectively. These frameworks should integrate diverse policy instruments, including informational, economic, and regulatory measures to promote sustainable biomass utilization (Nega et al., 2021). However, there are gaps in policy implementation due to overlapping responsibilities and inadequate coordination among stakeholders (Getnet et al., 2014). Institutions such as the Lake Tana and other water bodies protection and development agencies play a crucial role in managing water hyacinth in Ethiopia. They are responsible for implementing management strategies and coordinating efforts among stakeholders (Sewunet, Gizeyatu, et al., 2022). Nonetheless, institutional gaps exist due to bureaucratic inefficiencies and a lack of data management systems (Navarro and Phiri,2000). Stakeholder participation

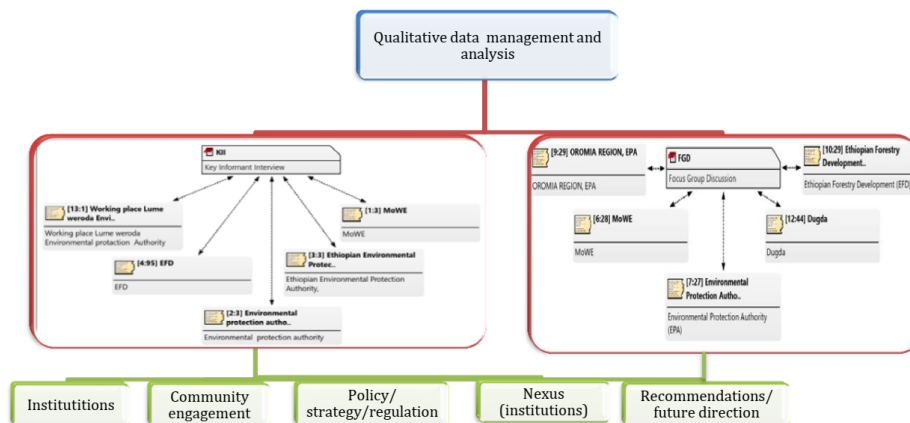
is critical for sustainable water hyacinth management. Studies have analyzed how local communities, government bodies, and NGOs collaborate in management efforts (Zikargae, 2022). However, there is a need for more comprehensive research on stakeholder roles and the development of frameworks that facilitate effective collaboration (Zikargae, 2022). There are notable gaps at the nexus of policy, institutions, and stakeholders in Ethiopia. These include insufficient integration of scientific research into policy-making, lack of stakeholder coordination, and inadequate institutional support for sustainable management practices (Dadhe et al, 2023).

The objective of the study is to assess the state and challenges of policy and regulations, institutions and community participation in the management of the water hyacinth and challenges of implementations. The study contributes for the development of robust policy frameworks that support sustainable water hyacinth management through regulatory measures, incentives for biomass utilization, and community engagement. It also provides empirical data for policy makers to enhance stakeholder participation and to strengthen institutional capacities to implement and monitor water hyacinth management programs effectively.

## **7.2 Methodology**

### **Data Collection**

The research employed a qualitative approach, focusing on the policy, institutions, and community aspects of water hyacinth management. The primary data collection technique involved conducting key informant interviews (KIIs) and (FGDs) with representatives from various organizations and institutes that play critical roles in this area. In total, 6 KIIs and FGDs were collected from several sectors found at the national, regional, and district offices at various levels, providing a comprehensive understanding of the diverse perspectives and experiences associated with water hyacinth management (Fig. 25).



**Figure 25.** Methodological framework to qualitative data management and analysis

The selection of key informants was purposive, targeting individuals with extensive knowledge and experience in water hyacinth management, policy formulation, and community engagement. This approach ensured that the data collected would be rich in detail and relevant to the research objectives. The interviews were semi-structured, allowing for flexibility in exploring specific themes while maintaining consistency across interviews. Each interview lasted approximately one hour, and all sessions were audio-recorded with the consent of the participants to ensure accuracy in data capture and transcription.

## Data Analysis

The analysis of the collected data followed a thematic approach, which is well-suited for exploring complex qualitative data sets. This method involves identifying, analyzing, and reporting patterns (themes) within the data, as described by Braun and Clarke (2006). The process began with the transcription of audio recordings into text, ensuring the integrity and precision of the data. Each transcript was then read multiple times to become thoroughly familiar with the content.

Open coding was employed during the initial phase of analysis, where segments of the text were labeled with codes that described their content. This process was iterative, with codes being refined and adjusted as new insights emerged from the data. Following open coding, axial coding was conducted to organize and relate codes to each other, forming categories that align with the research focus on policy, institutions, and community impact.

The themes were developed through constant comparison, where data from different interviews were compared to identify commonalities and differences. This method allowed for the identification of core themes that encapsulate the key findings of the research. The themes were then reviewed in relation to the

entire data set to ensure they accurately represented the informants' experiences and perspectives on water hyacinth management.

## **Methods and Tools for Data Analysis**

Data analysis was facilitated using Atlas.ti software, a qualitative data analysis (QDA) tool that supports the coding and organization of complex data sets. Atlas.ti was instrumental in managing the large volume of interview data, enabling efficient coding, sorting, and retrieval of information. The software's capabilities allowed for the detailed examination of themes and supported the visualization of relationships between different aspects of the data.

Additionally, the study utilized content analysis to complement thematic analysis. Content analysis provided a systematic method for quantifying the presence of specific words, phrases, or concepts within the qualitative data. This quantitative aspect of the analysis helped in identifying the frequency and significance of particular themes, thereby enhancing the depth and breadth of the findings. Content analysis was particularly useful in highlighting the prominence of certain policies and community responses within the dataset.

## **7.3 Results and Discussion**

This research explores the challenges and prospects in the management of invasive species, specifically water hyacinth (*Eichhornia crassipes*), in Ethiopia. Drawing from insights gathered from 6 key informants from government institutions dealing with water hyacinth from Federal, regional and woreda level this section discusses institutional priorities, strategies, resource allocation, and the effectiveness of current management practices.

### **7.3.1 Policy and Regulatory Support for Water Hyacinth Management**

This section presents the findings from interviews with various organizations regarding policy and regulatory support for water hyacinth management in Ethiopia. The discussion focuses on the effectiveness of existing policies, community involvement in policymaking, and recommendations for improving regulatory frameworks.

Ethiopia's approach to managing invasive species like water hyacinth is supported by a framework of policies and regulations aimed at environmental conservation and sustainable resource management.

Ethiopia has established several policies aimed at addressing the challenges posed by invasive species, including water hyacinth (*Eichhornia crassipes*). Key informants highlighted the following:

- **National Water Policy:** This policy emphasizes integrated water resource management and recognizes the need to control invasive species to protect water bodies. It provides a framework for local authorities to develop specific strategies for managing water hyacinth.
- **Environmental Protection Laws:** These laws mandate the assessment of environmental impacts caused by invasive species and require the involvement of local communities in management efforts.
- **Regional Initiatives:** Some regional governments have developed specific action plans targeting water hyacinth management. For example, the Oromia Regional State has initiated programs that include community engagement and capacity building.
- **Informants from the Ministry of Water and Energy** highlighted national strategies that integrate water hyacinth control into broader environmental policies. These include directives on aquatic ecosystem health and invasive species management.

The effectiveness of existing policies in controlling water hyacinth is mixed. The effectiveness varies significantly in practice. While the policies provide a foundational structure for management efforts, their practical effectiveness varies. Institutions like the Ethiopian Agricultural Transformation Agency play an active role in policy advocacy and formulation, working closely with governmental bodies to shape regulations that address the complexities of water hyacinth management. These efforts include engaging with local communities to raise awareness and gather input on policy needs.

Some communities have successfully engaged in management activities when supported by clear policies that outline their roles. For instance, initiatives that provide technical training have empowered communities to take action against water hyacinth infestations as per the informants from the Biodiversity Institute.

Despite these frameworks, Informants noted that while there are clear guidelines, the implementation often faces challenges due to resource constraints and lack of coordination among stakeholders. Informants identified several gaps in the current policy framework which include **Insufficient Integration:** there is a lack of integration between different policies affecting water resource management and invasive species control. This fragmentation leads to inefficiencies in addressing the multifaceted challenges posed by water hyacinth. Moreover, many policies are not grounded in empirical data regarding the effectiveness of various control methods. For example, while biological control methods have shown promise, there is insufficient research supporting their widespread application

Moreover, many informants reported that there is often a disconnect between policy formulation and on-the-ground implementation. For instance, while there are guidelines for community participation in

management efforts, many local communities remain unaware of their rights and responsibilities under these policies. Moreover, weak enforcement mechanisms hinder compliance with regulations. Informants indicated that without adequate monitoring and penalties for non-compliance, policies are often ignored.

Challenges encountered in implementing these policies include bureaucratic delays, limited inter-agency collaboration, and insufficient resources at the local level. These issues hinder both community and institutional efforts, reducing the overall impact of management strategies.

Community awareness of policies related to water hyacinth management is limited, with many informants pointing out the need for improved communication and education initiatives. Engaging communities in the policy-making process can be enhanced through participatory forums and workshops, allowing for input that reflects local challenges and needs.

To better support community efforts in managing water hyacinth, informants recommended:

- **Strengthening Local Governance:** Empowering local authorities with resources and training can facilitate more effective implementation of policies at the community level.
- **Enhancing Community Participation:** Developing mechanisms for community input during policy formulation can lead to more relevant and effective strategies.
- **Establishing Monitoring Frameworks:** Implementing robust monitoring systems can help assess policy effectiveness and adapt strategies as needed.

To better support community efforts, informants recommended several policy changes, including increased funding for community-based initiatives and enhanced training programs for local stakeholders. Regulatory changes needed include clarifying jurisdictional responsibilities and establishing stronger penalties for non-compliance.

Engagement with local communities in policy advocacy is crucial for effective water hyacinth management. Many informants reported that large number of community members is not fully aware of existing policies related to water hyacinth management. Informants suggested that awareness campaigns are necessary to educate communities about their roles in policymaking processes. Moreover, institutions can enhance community involvement by creating platforms for dialogue where community members can voice their concerns and contribute to policy formulation.

Empowering communities to participate in policy making can be achieved through structured engagement mechanisms, such as local advisory committees and public consultations. This involvement ensures that policies are responsive to the specific needs and conditions of affected areas.

For effective implementation and enforcement of regulatory changes, informants suggested the establishment of dedicated task forces at the regional level. These task forces would oversee compliance and coordinate efforts across different agencies and community groups.

The management of water hyacinth in Ethiopia is significantly influenced by existing policies and regulations. While there are frameworks designed to support community engagement and effective management strategies, gaps remain in implementation and enforcement. The management of water hyacinth in Ethiopia requires a robust policy framework that not only provides clear guidelines but also ensures practical implementation and community involvement. By addressing existing gaps and enhancing regulatory mechanisms, institutions can create a more effective and sustainable approach to managing this invasive species. Collaborative efforts between government, NGOs, private sectors and local communities are essential for achieving long-term success in combating water hyacinth.

### **7.3.2 Water Hyacinth management: Overview**

The management of water hyacinth (*Eichhornia crassipes*) has been approached using a variety of techniques across different countries, with three primary control methods being predominant: chemical, mechanical/manual removal, and biological control. Each of these methods, along with their combinations, has been applied with varying degrees of success globally (Villamagna and Murphy, 2010). Chemical control often involves the use of herbicides, which can be effective but may have environmental implications (Cilliers, 1991). Mechanical or manual removal, while labor-intensive, provides immediate physical removal of the biomass but is often limited in long-term efficacy (Gopal and Sharma, 1990). Biological control, which employs natural enemies of the plant such as weevils, offers a more sustainable approach, though it requires careful ecological consideration (Cilliers, 1991; Opande et al., 2004)

A critical aspect of sustainable management is effective nutrient management. Studies suggest that reducing nutrient influx into water bodies can significantly hinder the establishment and spread of water hyacinth by improving water quality and reducing conditions favorable for its growth (Jafari, 2010; Gezie et al., 2018; Dersseh et al., 2022)

In Ethiopia, specifically in Lakes Koka and Dembel, the primary strategy employed has been manual removal. However, this method has not resulted in a significant reduction in infestation; rather, it may even exacerbate the problem by spreading fragments that lead to further propagation (Addis and Desta, 2024; Nega et al., 2022). Experimental approaches have been initiated, such as utilizing the biomass for composting and exploring biological control methods (Karouach et al., 2022a).

The study reveals a fragmented approach in managing water hyacinth, with varying levels of engagement from stakeholders. Government bodies, NGOs, and international organizations are involved, but lack of coordination often hampers effective action. Informants recommended establishing a centralized task force to streamline efforts and enhance resource allocation.

Despite these efforts, insufficient attention has been given to addressing nutrient pollution from various sources, such as domestic, industrial, and agricultural runoff, which exacerbates the problem (Dersseh et al., 2022). Moreover, strategies to mitigate soil sedimentation from cropland runoff into these lakes remain underdeveloped. Although there are numerous technological solutions for biomass utilization that could offer economic benefits, local technologies, value chains, and market linkages have yet to be thoroughly evaluated (Delele et al., 2021).

In conclusion, the discussion with the key informants underscores the complexity of managing water hyacinth across different ecological and socio-economic landscapes. While traditional methods such as manual removal and chemical control provide immediate solutions, they often lack sustainability and can lead to unintended ecological consequences. Thus, the need for an integrated approach that incorporates nutrient management, innovative biocontrol measures, and the utilization of biomass for economic purposes is emphasized. An integrated management approach that combines these control methods with effective nutrient management and ecosystem-based strategies is widely acknowledged as the most effective means to sustainably manage water hyacinth and other invasive aquatic species. Such an approach not only addresses the immediate infestation but also tackles the underlying environmental conditions that favor the proliferation of water hyacinth (Charudattan, 1986). Collaborative efforts among institutions, stakeholders, and communities, alongside effective policy implementation, are essential to achieving long-term success in controlling this invasive species (ZIKARGA, 2018). Empowering local communities to participate in management efforts can enhance sustainability. Additionally, leveraging international expertise and resources can bolster capacity-building initiatives, providing a more resilient response to the water hyacinth challenge. The study highlights the importance of adapting strategies to local contexts and leveraging scientific research and community engagement to develop resilient management practices. Future strategies should focus on sustainable solutions that address both ecological and socio-economic impacts, ensuring the long-term health of Ethiopia's vital water bodies (Villamagna and Murphy, 2010).

### **7.3.3 Institutional Analysis in Water Hyacinth Management**

The study highlights that institutions in Ethiopia have diverse roles and responsibilities in managing water hyacinth, ranging from policy formulation to on-ground implementation. However, there is often a lack of

clear delineation of these roles, leading to overlapping responsibilities and inefficiencies. Key informants emphasized the need for a structured approach that prioritizes environmental issues based on their socio-economic impact, with water hyacinth management being a critical area due to its extensive impact on water resources and livelihoods (Nega et al., 2024).

It was also noted that Most institutions involved in environmental management prioritize water hyacinth management alongside other pressing environmental issues. However, the degree of prioritization varies significantly. For instance, organizations focused on aquatic biodiversity highlighted water hyacinth as a critical concern due to its rapid spread and ecological impact. In contrast, institutions dealing with broader environmental issues may view it as one of many challenges competing for limited resources (Onyari et al., 2024).

Institutions involved in environmental management often face the challenge of prioritizing water hyacinth management amidst other pressing issues. Key informants from the Ethiopian Biodiversity Institute noted that while biodiversity conservation is a broader priority, water hyacinth management is increasingly recognized due to its significant ecological and economic impacts. The Ministry of Water and Energy has similarly elevated the priority of water hyacinth management, integrating it into national water resource strategies.

Key informants indicated that long-term goals include achieving sustainable management of water bodies affected by water hyacinth, restoring native biodiversity, and enhancing community resilience. Institutions aim to establish integrated management frameworks that combine biological control methods with community engagement and education. For instance, the Ethiopian Agricultural Transformation Agency aims to develop community-based management programs that empower local stakeholders. Strategies include mechanical removal, biological control, and public awareness campaigns. These strategies are customized to regional contexts, addressing specific infestation levels and ecological conditions.

Most organizations have dedicated teams or departments focused on invasive species management within their environmental divisions. Institutions like the Environmental Protection Agency have dedicated departments for invasive species management, facilitating focused efforts on water hyacinth. Teams are structured to include environmental scientists, policy makers, and community liaison officers, ensuring a multidisciplinary approach. However, the effectiveness of these structures often depends on inter-agency collaboration and communication. Some institutions reported challenges in coordinating efforts across different levels of government and sectors.

The availability of technical resources such as research data, monitoring tools, and human expertise plays a crucial role in effective management. Capacity-building programs are essential for equipping staff with the necessary skills for effective management. Institutions that have invested in capacity-building programs reported better outcomes in managing water hyacinth. Training sessions on integrated pest management and community engagement strategies have been particularly beneficial. Capacity-building initiatives are essential for equipping staff with the necessary skills to manage invasive species effectively. Many institutions have implemented training programs focused on biological control methods and participatory management approaches. The Ethiopian Biodiversity Institute conducts regular training sessions on the latest management techniques and monitoring tools. These programs are crucial for sustaining long-term management efforts. However, while some capacity-building programs exist, they are not widespread or consistent. Key informants indicated that training programs are sporadic and not tailored to the specific needs of different regions. There is a need for comprehensive training programs that focus on both technical and managerial skills. Moreover, there is still a need for more extensive training opportunities to enhance staff competencies.

Institutions face several challenges, including limited financial resources, lack of public awareness, and insufficient technical expertise. Financial resources remain a constraint, with various institutions allocating limited budgets, often supplemented by international aid. Many institutions rely heavily on international aid, which is often project-specific and not sustained. Technical and human resources are also insufficient, with a lack of trained personnel to implement advanced management techniques. Informants emphasized the critical need for increased funding, advanced technical tools, and skilled personnel. Collaborative frameworks that involve local communities are also vital for addressing these challenges. Technical resources include the use of GIS mapping for monitoring infestations, while human resources are bolstered through partnerships with NGOs for community mobilization.

Monitoring and evaluation (M&E) are critical for assessing the success of water hyacinth management strategies. Institutions utilize various metrics such as changes in coverage area, biodiversity indices, and community participation rates to gauge effectiveness. Recent findings from the Ministry of Water and Energy reveal a 15% reduction in infestation areas due to targeted management efforts. However, many informants expressed concerns about the lack of standardized indicators across different organizations. Recent findings indicate that while some management strategies have yielded positive results such as reductions in water hyacinth coverage persistent challenges remain due to rapid regrowth facilitated by nutrient influx from upstream areas. Evaluation results are used to refine management strategies, ensuring adaptive management practices. Feedback loops allow for continuous improvement, with strategies being adjusted based on empirical data and stakeholder input.

Institutional strategies for managing water hyacinth in Ethiopia exhibit varying degrees of effectiveness. While progress is evident, particularly in reducing infestation levels, sustained success hinges on increased resource allocation and stakeholder engagement. By leveraging community involvement and international partnerships, Ethiopian institutions can enhance their capacity to manage this invasive species effectively. Moreover, by prioritizing integrated approaches that combine biological control with community engagement and robust monitoring systems, institutions can improve their effectiveness in addressing this invasive species' impact on aquatic ecosystems and local livelihoods.

To improve institutional effectiveness, it is crucial to streamline roles and responsibilities, enhance coordination mechanisms, and foster partnerships with stakeholders at all levels. Implementing transparent monitoring systems and fostering community involvement are also key to sustainable management.

These discussions provide a comprehensive overview of the institutional challenges and opportunities in managing water hyacinth in Ethiopia, highlighting the need for strategic planning and collaboration among all stakeholders involved.

The study on the management of water hyacinth in Ethiopia reveals a complex landscape of institutional roles, challenges, and opportunities. Key findings indicate that institutions face overlapping responsibilities and resource constraints, which hinder effective management. Financial limitations and insufficient technical and human resources are significant barriers, despite some capacity-building efforts. Successful collaborations, primarily between local governments and NGOs, demonstrate potential, yet coordination remains a challenge due to fragmented communication and planning.

Policy frameworks are often outdated, lacking the specificity and enforcement necessary to address current challenges. Institutions are pivotal in advocating for policy reforms, but bureaucratic inertia limits their effectiveness. Monitoring and evaluation efforts are sporadic, with integrated management approaches yielding the best results when consistently applied.

Future directions emphasize the integration of innovative technologies and the development of a national strategy that aligns with regional efforts. Recommendations include streamlining roles, enhancing coordination, fostering partnerships, and securing sustainable funding. Overall, the study underscores the importance of collaborative efforts and strategic planning to improve institutional effectiveness in the sustainable management of water hyacinth in Ethiopia.

### **7.3.4 Community Engagements in Water Hyacinth Management**

Communities play a critical role in water hyacinth management through direct participation in removal activities, monitoring infestations, and providing local insights. Mechanisms of involvement often include community meetings, participatory planning sessions, and local committees dedicated to environmental management. Key informants highlighted the importance of including community voices in decision-making processes to ensure that management strategies are culturally appropriate and widely accepted

Community members are responsible for the on-ground implementation of management strategies, including manual removal of the weed, regular monitoring of infestation levels, and participating in educational outreach programs. Their active involvement is crucial for the sustainable management of water hyacinth. Responsibilities are shared among governmental bodies, NGOs, and local communities. Informants stressed the importance of community involvement in monitoring efforts, which enhances accountability and effectiveness.

Institutions actively engage local communities in water hyacinth management through various participatory approaches. Informants from the Ethiopian Biodiversity Institute highlighted initiatives that involve community members in manual removal and monitoring of water hyacinth infestations. These activities are complemented by awareness campaigns that educate the public on the ecological and economic impacts of the invasive species.

Local institutions provide essential support to communities, including technical assistance, financial resources, and training programs. The Ethiopian Agricultural Transformation Agency has been instrumental in offering technical training on sustainable management practices. Financial support is often provided through partnerships with international NGOs, facilitating the procurement of necessary tools and resources for effective management.

The support provided by local institutions has proven effective in enhancing community efforts. Informants observed increased community engagement and improved outcomes in areas where technical training and financial resources were readily available. The success of these initiatives underscores the importance of robust institutional support in fostering community participation.

Several community-based initiatives have been successful, with informants citing the "Koka Dam Restoration Project" as a notable example. This initiative, supported by the Ministry of Water and Energy, involved local communities in coordinated removal efforts and reforestation activities. Key factors contributing to success included strong leadership, adequate funding, and continuous training. Success indicators for these initiatives include reduced water hyacinth coverage and improved water quality.

Community-led initiatives have yielded positive outcomes, such as the restoration of local fisheries and increased biodiversity in previously infested areas. An inspiring success story is that of the Ziway Lake Community Group, which successfully reduced water hyacinth coverage by 40% through consistent monitoring and manual removal efforts.

Institutions face challenges such as limited resources and logistical constraints in involving communities. Community members often struggle with inadequate funding and a lack of technical expertise, which can hinder their participation. Informants noted that these challenges impact the overall effectiveness of community involvement, as they limit the scope and sustainability of management efforts. While community awareness of policies related to water hyacinth management is generally low, there is a growing recognition of the importance of involving communities in policy discussions. Existing policy gaps include a lack of inclusive frameworks that integrate community input into decision-making processes.

To enhance community involvement, institutions should focus on building stronger partnerships with local leaders and providing ongoing training and resources. Informants recommended leveraging technology for better communication and coordination among stakeholders. Additionally, fostering a sense of ownership among community members can drive sustained engagement and commitment. Key strategies for enhancing community involvement include establishing clear roles and responsibilities, engaging youth and women in management activities, and integrating traditional knowledge into modern management practices. By empowering communities with the necessary tools and knowledge, water hyacinth management efforts can become more effective and sustainable.

Encouraging community input can lead to more effective and sustainable policies. Key informants suggested mechanisms such as public consultations and participatory policy development workshops to bridge the gap between policymakers and local communities. Sustainability is a major concern, with many initiatives lacking long-term support and resources. Ensuring sustainable community participation involves embedding management practices within local traditions and securing ongoing funding and technical assistance.

The study highlights the critical role of communities in managing water hyacinth in Ethiopia, emphasizing the need for greater support, collaboration, and policy integration. Community participation is a cornerstone of successful water hyacinth management in Ethiopia. While challenges remain, the successes achieved through collaborative efforts demonstrate the potential for meaningful impact. By continuing to support and empower local communities, institutions can enhance the effectiveness of their management strategies and contribute to the long-term health of Ethiopia's aquatic ecosystems. Moreover,

key recommendations include increasing financial investment, enhancing technical training, and fostering international collaborations. Additionally, improving public awareness campaigns can garner broader support for management initiatives. Additionally, evaluating the effectiveness of different community participation models across diverse ecological and socio-economic contexts can provide valuable insights for improving management practices. Future plans include scaling successful community initiatives and integrating them into broader regional strategies. Long-term goals emphasize building resilient communities capable of independently managing water hyacinth through enhanced education and resource access

### **7.3.5 Institutional Collaboration in Water Hyacinth Management**

This section synthesizes findings from the key informant interviews with various organizations, regarding the nexus between institutions, community engagement, and regulations in managing water hyacinth (*Eichhornia crassipes*) in Ethiopia. The discussion highlights collaboration strategies, the synchronization of efforts, communication channels, and recommendations for improving management practices.

Institutions involved in water hyacinth management in Ethiopia collaborate with local, national, regional, and international bodies to tackle this invasive species. Institutions in Ethiopia engage in various collaborative efforts to manage water hyacinth effectively. Key informants noted that collaboration occurs at local, national, regional, and international levels:

**Local Collaborations:** Many NGOs work directly with communities to implement management strategies. For instance, the Lake Tana Biosphere Reserve collaborates with local fishing communities to monitor water hyacinth growth and promote sustainable fishing practices.

**National Partnerships:** Government agencies often partner with research institutions to conduct studies on the ecological impacts of water hyacinth. The Ethiopian Institute of Agricultural Research has been pivotal in providing scientific data to guide policy decisions.

**International Cooperation:** Regional initiatives involving countries like Kenya, Uganda, and Tanzania facilitate knowledge sharing and joint management strategies for water hyacinth across borders (Nicol et al., 2015). Informants from the Ministry of Water and Energy reported partnerships with NGOs and international organizations such as the UN Environment Programme to align efforts and resources. These collaborations leverage diverse expertise and funding to enhance management strategies (Tramberend et al., 2019).

Community efforts often align with institutional strategies through participatory approaches that integrate local knowledge and practices. The Ethiopian Biodiversity Institute emphasized the importance of aligning community-led initiatives with broader institutional frameworks to ensure cohesive action.

Community efforts are increasingly aligning with institutional strategies for managing water hyacinth. Informants reported that local communities are engaged in manual removal efforts that complement institutional initiatives. For example, Community members participate in organized removal campaigns funded by NGOs, which align with national policies aimed at reducing water hyacinth coverage. Moreover, Institutions support community-led awareness campaigns about the ecological impacts of water hyacinth, fostering a sense of ownership among residents.

Examples of successful collaborations include partnerships with research institutions that provide scientific insights and technological solutions for more effective management. These collaborations have led to innovative approaches, such as biological control methods that reduce reliance on chemical treatments.

Mechanisms such as joint task forces and regular stakeholder meetings facilitate synchronization between communities and institutions. Successful examples include the "Koka Dam Initiative," where local communities, government agencies, and NGOs jointly managed water hyacinth removal.

Several mechanisms exist to synchronize community and institutional efforts. These include Steering Committees and workshops. Some regions have established steering committees that include representatives from communities, NGOs, and government bodies to coordinate management activities. Workshops are held periodically to update stakeholders on progress and challenges in managing water hyacinth. These forums facilitate dialogue and information sharing.

Key factors contributing to successful collaborations include effective communication, shared goals, and access to resources. Informants highlighted the role of technology in improving coordination, such as using mobile apps for real-time data sharing on infestation levels.

Existing communication channels include community workshops, digital platforms, and liaison officers who bridge gaps between stakeholders. However, informants noted that these channels often lack consistency and reach, suggesting the need for more robust and inclusive communication strategies.

Balancing resource allocation between community-led and institutional efforts involves trade-offs, particularly in funding and manpower. Institutions strive to balance immediate removal efforts with long-term sustainability strategies by integrating prevention measures into community education programs.

Challenges in coordinating efforts include bureaucratic hurdles, differing priorities among stakeholders, and limited resources. Informants suggested that creating a centralized coordination body could streamline efforts and reduce duplication of activities.

Balancing resources between community-led initiatives and institutional management efforts presents challenges. Informants noted that limited funding often leads to competition between community projects and institutional priorities. For example, when funds are directed towards large-scale institutional projects, community initiatives may suffer from neglect. In order to avert these problems, there is a need to develop funding models that allocate resources based on joint proposals from both communities and institutions can ensure equitable distribution. Regulatory challenges often hinder effective management, with informants citing unclear jurisdictional roles and insufficient enforcement as major barriers.

Strategies to improve synchronization involve establishing shared objectives and clear communication pathways. Regular stakeholder meetings and joint planning sessions can ensure alignment and facilitate collective decision-making.

Effective resource sharing models include pooled funding mechanisms and shared technical training programs. These frameworks enable communities and institutions to access resources equitably, enhancing overall management capacity.

Current policies provide a foundation for synchronized efforts, but informants identified gaps in enforcement and community involvement. Long-term plans should focus on sustainable management practices, integrating traditional knowledge with scientific advancements.

Recommendations include enhancing policy support for community initiatives, investing in capacity-building programs, and fostering international partnerships to leverage global expertise. Practical implementation can involve pilot projects that test innovative management approaches and scale successful models.

Innovations such as using drones for monitoring infestations and employing community-based monitoring networks can improve synchronization efforts. These innovations can be tested through pilot programs and scaled based on their effectiveness and adaptability in local contexts.

The management of water hyacinth in Ethiopia requires a multifaceted approach involving collaboration among institutions, communities, and policymakers. By fostering collaboration, enhancing communication, and aligning policy support, stakeholders can create a more coordinated and sustainable approach to addressing this invasive species. Continued innovation and resource sharing are essential for achieving long-term success. While there have been successes in synchronizing efforts through

established mechanisms, challenges remain regarding resource allocation and regulatory barriers. By fostering stronger partnerships and improving communication channels, Ethiopia can enhance its capacity to manage invasive species effectively.

## **7.4 Conclusion and Recommendations**

### **Conclusion**

The management of water hyacinth in Ethiopia presents a multifaceted challenge that is deeply intertwined with existing policy frameworks, institutional capabilities, and community dynamics. Despite the presence of comprehensive policies aimed at controlling this invasive species, the study reveals substantial gaps in implementation, enforcement, and stakeholder coordination. The effectiveness of Ethiopia's National Water Policy and Environmental Protection Laws is undermined by insufficient resource allocation and weak enforcement mechanisms, leading to fragmented management efforts.

The research underscores the pivotal role of community involvement in water hyacinth management. Successful management cases demonstrate that when communities are empowered with clear policies, technical training, and resources, they can actively contribute to control efforts. However, widespread success remains elusive due to limited awareness and engagement among many local communities. The disconnect between policy formulation and on-ground action exacerbates this issue, necessitating improved communication and participatory frameworks that include local voices in the policy-making process.

Institutional challenges further complicate water hyacinth management in Ethiopia. Overlapping responsibilities, limited inter-agency collaboration, and resource constraints hinder effective action. While some institutions prioritize water hyacinth management, others view it as just one of many competing environmental challenges. This lack of unified prioritization results in inefficiencies and reduced impact of management strategies.

Management techniques currently employed, such as manual removal, offer immediate but temporary solutions. The study highlights the need for an integrated approach that combines biological control, nutrient management, and community involvement. Addressing nutrient pollution and enhancing ecosystem health are critical for sustainable management. By focusing on these underlying environmental conditions, Ethiopia can create a more resilient framework for combating water hyacinth and other invasive species.

## **Recommendations**

The following are the recommendations of the study

1. **Strengthening Local Governance and Community Involvement:** Empower local authorities with resources and training to implement policies effectively. Develop mechanisms for community input during policy formulation and implementation, ensuring strategies are contextually relevant and effective.
2. **Enhance Coordination and Resource Allocation:** Establish centralized task forces to streamline efforts, improve inter-agency collaboration, and enhance resource distribution. Increase funding and technical support to bolster institutional capacity and innovation in water hyacinth management.
3. **Implement Comprehensive Training Programs:** Conduct regular capacity-building initiatives focused on integrated pest management and participatory approaches. Equip stakeholders with the necessary skills and knowledge to manage invasive species effectively.
4. **Focus on Sustainable Management Techniques:** Emphasize nutrient management, biological control, and biomass utilization to foster long-term ecological balance and economic benefits. Reduce nutrient influx into water bodies to mitigate conditions that favor water hyacinth growth.
5. **Leverage International Expertise and Resources:** Collaborate with international organizations to enhance capacity-building initiatives and provide a more resilient response to the water hyacinth challenge. Foster partnerships that bring in global best practices and innovative solutions.

## Chapter 8: Synthesis, Conclusion and Recommendations

### 8.1 Synthesis

#### 8.1.1 State of Water Hyacinth and Sustainable Development

Water hyacinth, an aquatic plant originally native to the Amazon basin, has earned a notorious reputation as one of the world's most invasive species. Its rapid proliferation across tropical regions poses significant challenges to sustainable development. This review synthesizes existing research on water hyacinth's complex interactions with the environment, its economic implications, and its influence on human well-being.

Globally, water hyacinth's impact is multifaceted. On the one hand, it offers potential benefits by providing economic resources for local communities. In several regions, the plant is harvested and utilized for products such as biofuel, animal feed, and even handicrafts. Its ability to absorb pollutants from water bodies positions it as a natural ally in pollution reduction efforts. These attributes underscore the plant's potential role in supporting SDG 6, which focuses on clean water and sanitation, and SDG 12, which emphasizes responsible consumption and production (Lamichhane et al., 2024).

However, the negative consequences of water hyacinth overshadow its benefits, particularly in developing countries with limited resources to manage invasive species. In Ethiopia, for instance, the plant has clogged waterways, obstructing transportation and fishing activities, which are crucial to local livelihoods. This disruption has economic repercussions, heightening food insecurity and poverty, thereby impeding SDG 1 (no poverty) and SDG 2 (zero hunger) (Stebek, n.d.; Echendu, 2020).

Moreover, the ecological impacts are profound. Water hyacinth forms dense mats on water surfaces, depleting oxygen levels and disrupting aquatic ecosystems. This affects biodiversity and the provision of ecosystem services, which are vital for maintaining ecological balance. The plant's spread also exacerbates water loss through increased evaporation, conflicting with efforts to conserve water resources amid changing climate conditions (Masifwa et al., 2001).

The synthesis highlights a critical gap in effective policy and resource allocation for managing water hyacinth proliferation. Current strategies are often reactive rather than proactive, lacking the comprehensive, integrated approach necessary for sustainable management. Policymakers must prioritize the development of invasive species management plans that align with the SDGs, leveraging both technological innovations and traditional knowledge (Halmy, 2024; Roy et al., 2023).

Addressing the challenge of water hyacinth requires a concerted global effort. Collaboration among governments, non-governmental organizations, private sectors and local communities is essential to implement sustainable practices and policies. Investment in research and development, coupled with education and awareness campaigns, can empower affected regions to harness the plant's benefits while mitigating its adverse impacts.

The state of water hyacinth underscores the need for a balanced approach that acknowledges both its potential advantages and its significant drawbacks. By aligning management strategies with the SDGs, stakeholders can work towards a future where water hyacinth contributes positively to societal and environmental well-being rather than serving as a barrier to sustainable development.

### **8.1.2 Temporal Trends of Water Hyacinth**

The analysis of land-use and land-cover (LULC) change in the Dembel and Koka catchments offers a revealing glimpse into the evolving ecological and environmental challenges these areas face. Historically, these areas have been characterized by a rich tapestry of biodiversity and a delicate balance between human activity and natural ecosystems. However, recent trends indicate a shift that threatens this equilibrium, with the proliferation of water hyacinth and increasing urbanization at the forefront of this transformation.

Traditionally, the Dembel and Koka catchments have supported diverse ecosystems, with wetlands playing a critical role in maintaining biodiversity and water quality (CARP et al., 2020). Water hyacinth, once a relatively minor presence, has now become a dominant invasive species. Historically, its spread was limited by natural controls and lower levels of human-induced environmental change. However, as agricultural practices intensified and urban areas expanded, the natural barriers to their spread diminished. This allowed water hyacinth to establish itself more aggressively, beginning a trend that has had profound impacts on local ecology (Hazell and Wood, 2008; Pretty and Bharucha, 2014).

In the present day, the challenges posed by water hyacinth are compounded by rapid urbanization and agricultural expansion. In Dembel Lake, the unchecked growth of water hyacinth is altering aquatic ecosystems, outcompeting native plant species, and degrading water quality. The resulting shifts in aquatic biodiversity threaten the survival of native species and disrupt the ecological balance. Furthermore, the expansion of agricultural land raises concerns about sustainability and land degradation, as natural habitats are converted to farmland, reducing biodiversity and increasing soil erosion.

Koka catchment is experiencing similar pressures, with urbanization advancing at a breakneck pace. This urban sprawl not only encroaches on natural habitats but also increases pollution and alters hydrological

cycles. The presence of water hyacinth exacerbates these issues, as its dense mats restrict water flow, reduce oxygen levels, and increase evaporation rates, further stressing already vulnerable ecosystems.

Looking towards the future, the trends observed in the Dembel and Koka catchments suggest an urgent need for integrated land-use planning and effective management strategies. The continued spread of water hyacinth, coupled with the pressures of urbanization and agricultural expansion, highlights the complexity of balancing development with environmental sustainability. Without intervention, the ecological integrity of these catchments could be irreversibly compromised.

Future strategies must prioritize the preservation of biodiversity and water quality while accommodating the needs of growing human populations. This requires a multifaceted approach, incorporating technological innovations, policy interventions, and community engagement. For instance, biological control methods and mechanical removal of water hyacinth can help manage its spread. Concurrently, urban planning must incorporate green spaces and buffer zones to protect natural habitats from encroachment.

Moreover, agricultural practices should be re-evaluated to promote sustainable land use, reducing the reliance on extensive land conversion and minimizing environmental degradation. Encouraging agroforestry and sustainable farming techniques can help maintain soil health and biodiversity.

The temporal trends of water hyacinth and land-use change in the Dembel and Koka catchments illustrate the delicate balance between human development and ecological preservation. The past and present challenges underscore the need for comprehensive strategies that align with sustainable development goals. By addressing the root causes of ecological degradation and promoting sustainable practices, it is possible to forge a path towards a future where both human and natural systems can thrive in harmony.

### **8.1.3 Key land-use dynamics**

Deforestation, the act of clearing forests for various purposes, disrupts the delicate structure of soil, making it more prone to erosion. As the soil is stripped away, it carries with it nutrients that end up in nearby water bodies. This nutrient-rich runoff creates ideal conditions for the rapid growth of water hyacinth, an invasive plant species. Similarly, agricultural expansion, while boosting economic development, introduces another challenge. The widespread use of fertilizers in farming leads to nutrient runoff, which, when washed into rivers and lakes, provides a fertile ground for the flourishing of water hyacinth. As urban areas grow, impervious surfaces like roads and buildings increase, preventing rainwater from naturally soaking into the ground. Instead, stormwater runoff is channeled into water bodies, bringing with it pollutants, including nutrients. This runoff further promotes the spread of water

hyacinth, contributing to its dominance in aquatic ecosystems. Finally, wetlands, which once acted as natural filters, are increasingly degraded due to land-use changes. These vital ecosystems help regulate the flow of nutrients and sediments into water bodies, but their loss amplifies nutrient pollution. As a result, the absence of wetlands accelerates the conditions that allow water hyacinth to thrive, aggravating the challenges posed by this invasive species.

Climate change is exacerbating the spread of water hyacinth in significant ways. Shifts in climate patterns, particularly increased rainfall and fluctuating temperatures, contribute to heightened nutrient loading in water bodies. As rainfall intensifies, more nutrients are washed into rivers and lakes, creating the perfect conditions for water hyacinth to thrive. These climate-induced changes also disrupt natural hydrological cycles, further promoting the plant's proliferation. At the same time, overexploitation of water resources, whether for irrigation, agriculture, or urban consumption, leads to lower water levels. As water becomes scarcer, the concentration of nutrients in water bodies increases, providing a nutrient-rich environment that accelerates the growth of water hyacinth. In areas where water scarcity is already a challenge, this only compounds the issue. The spread of water hyacinth and the degradation of ecosystems caused by land-use changes (LULCC) are contributing to the alarming loss of biodiversity. Water hyacinth, being an invasive species, competes with native plants and disrupts local food chains. As a result, both aquatic and terrestrial ecosystems suffer, impacting wildlife and the human populations who depend on these ecosystems for food, resources, and livelihood. The socioeconomic impacts are also profound. In areas where fishing and transportation rely on water bodies, the presence of water hyacinth can obstruct these activities, threatening food security and disrupting trade. Moreover, in regions that rely on tourism tied to lakes, rivers, or wetlands, the aesthetic and ecological degradation caused by the plant can result in reduced visitor numbers, leading to significant economic losses. Health-wise, the growth of water hyacinth presents a clear danger. Stagnant water clogged with the plant provides an ideal breeding ground for mosquitoes, increasing the risk of waterborne and vector-borne diseases such as malaria. Additionally, the rapid growth of the plant can significantly degrade water quality, posing a direct threat to the health of local populations who rely on these water bodies for drinking, bathing, and agricultural needs.

An effective approach to combating the spread of water hyacinth requires integrated land-use management, one that takes into account a wide range of environmental factors. By incorporating sustainable farming practices, forest conservation efforts, and urban planning that prioritizes environmental health, we can reduce the underlying causes that promote water hyacinth growth. This holistic approach ensures that land use doesn't contribute to the degradation of ecosystems, but instead fosters a balanced relationship between development and nature. Technological advancements also offer

significant potential for more targeted and effective management of water hyacinth. Remote sensing and Geographic Information Systems (GIS) can be employed to track and predict the spread of the plant across vast water bodies. By identifying patterns and assessing environmental conditions, these tools enable authorities to monitor hyacinth proliferation in real time and direct management efforts where they are most needed, saving both time and resources. Moreover, community engagement plays a crucial role in the success of conservation efforts. Local communities are often the first to witness the effects of water hyacinth and the most impacted by its spread. Therefore, involving them in both monitoring and managing its growth is vital. Through awareness campaigns and active participation, communities can help maintain the sustainability of conservation efforts, ensuring that solutions are not only effective but also widely supported and adopted. With a united approach combining integrated land-use management, technological tools, and community involvement there is a strong foundation for tackling the spread of water hyacinth and protecting aquatic ecosystems.

#### **8.1.4 Environmental Impacts of Water Hyacinth**

The environmental challenges posed by water hyacinth in Lakes Koka and Dembel stem largely from nutrient pollution caused by agricultural runoff and industrial effluents. These pollutants lead to eutrophication, which promotes algal blooms and oxygen depletion, threatening aquatic life. Water hyacinth thrives in nutrient-rich waters, worsening the situation by blocking sunlight, reducing biodiversity, and disrupting local economies, particularly fishing and tourism.

The plant's impact on livelihoods is significant, especially for farmers reliant on the lakes for irrigation. The dense mats impede water flow, affecting crop yields and reducing agricultural income. While its effect on livestock and fish income is minimal, its presence hampers off-farm activities like transportation and tourism, with economic repercussions for local communities.

Studies have shown that socio-economic factors, such as education and experience, influence how communities adapt to water hyacinth's challenges. Engaging local communities in management strategies can lead to more sustainable solutions. Holistic approaches that combine ecological and socio-economic considerations are essential for addressing the problem effectively.

#### **8.1.5 Willingness to Engage in Water Hyacinth Management**

In the Central Rift Valley Lakes of Ethiopia, the challenge of managing invasive water hyacinth presents both an ecological and socio-economic conundrum. A recent study delves into the intricate dynamics of household willingness to engage in control projects for this pervasive weed. While labor is abundant in these communities, the study underscores that relying solely on manual labor is insufficient for effective

management. Instead, it proposes a more nuanced approach that considers various socio-economic factors, including age, sex, education, and wealth, which significantly influence participation preferences.

The willingness of households to participate in water hyacinth management is not uniform. Age, for instance, plays a critical role, as younger individuals may be more inclined toward physically demanding tasks or innovative solutions. Conversely, older community members might prefer contributing through less physically intensive means, such as financial donations or advisory roles based on their experience and knowledge.

Gender also influences participation. Women, often the backbone of household management, may have different priorities and time constraints compared to men. Understanding these gender dynamics is crucial for designing inclusive management strategies that leverage the strengths and capacities of all community members.

Education and wealth further impact participation preferences. More educated individuals might be inclined toward roles that involve planning, coordination, or technical input, while those with greater financial resources may prefer to contribute through monetary donations or the provision of machinery and chemicals. Recognizing these diverse preferences allows for a more tailored approach to community engagement.

The study suggests that diversifying participation options is key to aligning management efforts with community needs. This could involve offering various roles that cater to different skill sets and capacities. For example, community members could participate by hiring labor, donating machinery or chemicals, or engaging in awareness campaigns and educational programs.

By providing multiple avenues for participation, the project can tap into a broader pool of resources and expertise. This not only enhances the effectiveness of water hyacinth management but also fosters a sense of ownership and responsibility among community members, increasing the likelihood of sustained engagement.

Local resources and knowledge are invaluable assets in the fight against water hyacinth. The study highlights the potential to transform this invasive species from a burden into an opportunity through innovative utilization strategies. For instance, water hyacinth can be harvested and used for biofuel production, animal feed, or even crafting materials.

Engaging local communities in these innovative practices not only alleviates the ecological impact of water hyacinth but also provides economic benefits. By creating new income-generating opportunities, communities can enhance their livelihoods while contributing to environmental sustainability.

The synthesis of findings indicates that successful water hyacinth management requires a multifaceted approach that acknowledges the diverse socio-economic backgrounds of local communities. By recognizing individual preferences and capacities, management projects can enhance community engagement and effectiveness.

### **8.1.6 Stakeholders' Engagement in Water Hyacinth Management**

The management of water hyacinth in Ethiopia presents a multifaceted challenge that involves policy implementation, stakeholder coordination, and community engagement. Despite the existence of comprehensive policies aimed at controlling this invasive species, the effectiveness of these measures is often compromised by several critical issues. The study identifies significant gaps in policy enforcement, resource allocation, and institutional collaboration, which hinder the successful management of water hyacinth.

Ethiopia has established policies designed to address the proliferation of water hyacinth, yet the implementation and enforcement of these policies remain weak. One of the primary challenges is the insufficient allocation of resources, which limits the capacity of institutions to carry out effective management strategies. Without adequate funding and personnel, even the most well-intentioned policies can fall short of achieving their objectives.

Enforcement mechanisms are another area of concern. The lack of robust systems to ensure compliance with regulations means that policies often fail to translate into tangible action. Strengthening enforcement through increased monitoring and accountability is essential for bridging the gap between policy and practice.

The successful management of water hyacinth requires the active involvement of various stakeholders, including government agencies, non-governmental organizations, and local communities. However, the study highlights significant challenges in stakeholder coordination. Overlapping responsibilities among government agencies often lead to inefficiencies and confusion, while limited inter-agency collaboration further complicates efforts.

Community involvement is crucial for effective management, yet awareness and engagement at the grassroots level are limited. Many community members lack knowledge about the ecological and economic impacts of water hyacinth, reducing their motivation to participate in control efforts. Enhancing community education and involvement is vital for fostering a collective approach to management.

Institutional challenges, such as overlapping responsibilities and limited collaboration, exacerbate the difficulties in managing water hyacinth. These challenges highlight the need for clear delineation of roles

and responsibilities among stakeholders. Establishing effective communication channels and fostering collaboration across agencies can enhance coordination and resource-sharing, leading to more efficient management strategies.

Current management techniques, such as manual removal, provide only temporary solutions. While these efforts can reduce the immediate impact of water hyacinth, they do not address the underlying causes of its proliferation. The study emphasizes the need for an integrated approach that combines manual removal with biological control methods, nutrient management, and community involvement.

The synthesis of the study underscores the complex interplay between policy frameworks, institutional capabilities, and community dynamics in managing water hyacinth. To move forward, Ethiopia must develop cohesive strategies that integrate local voices into policy making and enhance institutional collaboration. By involving communities in decision-making processes, policies can become more relevant and effective at the local level.

Addressing nutrient pollution, a key driver of water hyacinth proliferation, is essential for promoting ecosystem health. Implementing sustainable agricultural practices and improving waste management can reduce nutrient runoff, creating conditions less favorable for water hyacinth growth.

In conclusion, managing water hyacinth in Ethiopia requires a multifaceted approach that addresses policy implementation, stakeholder coordination, and community engagement. By strengthening institutional capabilities and fostering collaboration, Ethiopia can create a resilient framework for managing water hyacinth and other invasive species. This holistic approach not only addresses the immediate challenges but also lays the groundwork for sustainable environmental management in the future.

## **8.2 Conclusion**

The invasive nature of this plant presents significant ecological and socio-economic challenges, yet it also holds potential for positive contributions if managed wisely. Addressing the water hyacinth problem requires coordinated global action that integrates knowledge, technology, and financial resources.

Water hyacinth management is not a localized issue but a global challenge that demands a unified response. International cooperation can facilitate the sharing of best practices, technologies, and funding to support affected regions. However, to translate global strategies into actionable solutions, local communities must be actively involved. Their participation is essential in adapting global knowledge to fit regional contexts and in implementing sustainable practices that align with local needs.

The ecosystems of the Dembel and Koka catchments are at a critical juncture, threatened by invasive species and rapid urban development. These pressures necessitate immediate intervention to protect aquatic ecosystems and ensure sustainable land use. Collaborative efforts among stakeholders, including government agencies, non-governmental organizations, private sectors and local communities, are crucial for addressing these challenges.

To safeguard the ecological health of the catchments, stakeholders must prioritize initiatives that balance development with conservation. This includes promoting sustainable land-use practices, implementing effective waste management systems, and integrating water hyacinth control methods that combine mechanical, biological, and chemical approaches.

The feedback loop between land-use and land-cover changes (LULCC) and water hyacinth proliferation presents a formidable environmental challenge in Ethiopia's Rift Valley. Breaking this cycle requires sustainable land management practices that address the root causes of nutrient pollution and habitat degradation. Controlled fertilizer use, reforestation, and wetland restoration are essential components of a strategy aimed at interrupting this cycle and restoring ecological balance.

Without intervention, the degradation of these ecosystems will continue, further diminishing ecosystem services and driving additional land cover changes. By focusing on sustainable land management, Ethiopia can mitigate the impacts of LULCC and promote the resilience of its natural environments.

Preserving the ecological integrity of Lakes Koka and Dembel demands an urgent, multifaceted strategy. This includes implementing sustainable agricultural practices that minimize nutrient runoff, upgrading wastewater treatment facilities to reduce pollution, and employing a comprehensive approach to water hyacinth management. Community engagement and education are critical in fostering sustainable practices and achieving long-term ecological balance.

By involving local communities in decision-making processes and providing education on sustainable practices, stakeholders can ensure that management strategies are both effective and culturally appropriate. This engagement is vital for building community resilience and encouraging stewardship of natural resources.

The impact of water hyacinth on rural livelihoods in Lake Dembel and Lake Koka extends beyond agricultural income, affecting social behaviors and ecological dynamics. The findings of this study provide crucial insights for formulating effective invasive weed management policies in Ethiopia's Rift Valley and beyond. Policies must consider the socio-economic dimensions of water hyacinth management, ensuring that interventions support the well-being of local communities.

A diversified approach to community involvement in water hyacinth control is essential for aligning projects with local needs and capacities. By considering factors such as age, sex, education, and wealth, management efforts can be more effectively tailored to community dynamics. Incorporating lessons from other countries can further enhance these efforts by transforming challenges into opportunities.

Ethiopia must adopt a holistic approach to water hyacinth management that strengthens local governance, enhances coordination, and focuses on sustainable management techniques. By integrating community involvement and leveraging international expertise, Ethiopia can improve its response to the water hyacinth problem and foster long-term ecological balance.

Furthermore, the study highlights the need for a comprehensive, integrated approach to water hyacinth management that addresses the ecological, socio-economic, and institutional dimensions of the issue. By fostering collaboration, enhancing governance, and promoting sustainable practices, Ethiopia can turn the challenge of water hyacinth into an opportunity for ecological and economic resilience.

## **8.3 Recommendations**

### **The study proposes the following recommendations**

**Multidisciplinary Research:** Effective water hyacinth management requires a multifaceted approach, integrating in-depth research, diverse control methods, strong local governance, and national policy integration. Expanding research initiatives led by universities and research institutions is crucial for uncovering new management techniques, ecological effects, and utilization methods. These insights can guide better management practices, benefiting researchers, policymakers, and communities alike. Additionally, employing a mix of mechanical, manual, biological, and chemical control methods, coordinated by environmental agencies and local governments, increases the chances of success. This integrated approach helps restore local ecosystems and reduces the pressure of invasive species. Strengthening local governance and community involvement by empowering local authorities, providing resources, and establishing mechanisms for community input ensures that management strategies are contextually relevant and sustainable. National governments and international partners must support these efforts to build local capacity. Finally, integrating invasive species management strategies into national policies, guided by global best practices, can help address the complexities of water hyacinth control while promoting environmental regulation and income generation.

**Engaging relevant stakeholders in water hyacinth management:** Effective management and sustainability of water hyacinth control efforts require active community engagement, coordinated stakeholder collaboration, and inclusive participation. Raising awareness through campaigns and participatory workshops, led by local NGOs and community organizations, is essential for educating communities about the impacts of water hyacinth. This awareness fosters proactive, united efforts in managing the issue. Additionally, creating stakeholder committees to oversee and coordinate conservation activities can maximize the effectiveness of these efforts, with involvement from government agencies, environmental NGOs, industries, researchers, local communities, and policymakers. By fostering collaboration and leveraging the strengths of diverse stakeholders such as labor, machinery, and chemical support local governments and NGOs can create platforms for community participation. This approach not only enhances water hyacinth management but also empowers local communities, providing them with opportunities to contribute in ways that align with their capabilities and fostering ownership and commitment to the conservation of a healthier ecosystem.

**Training and Awareness:** Education and training empower communities to use water hyacinth in innovative ways, transforming a challenge into an economic opportunity. To put into effect, organize workshops and training sessions drawing on international examples of water hyacinth utilization. Local educational institutions and international partners can facilitate these programs. Community members who gain skills for alternative livelihood opportunities, enhancing economic resilience will be benefited

**Tailored Approaches:** Socio-economic diversity within communities means that a one-size-fits-all approach is ineffective. This is implemented by designing management strategies that consider age, sex, education, and wealth, using community surveys and participatory planning sessions. Community leaders and social scientists should lead these efforts. All community sectors, as strategies are more likely to succeed when aligned with individual preferences and capacities, will greatly benefit.

**Implement Integrated Soil and Water Conservation and sustainable agricultural practices:** Conservation practices and sustainable agricultural practices are essential to mitigate the ecological impacts of water hyacinth and urbanization. These practices reduce nutrient runoff and enhance ecosystem health. Farmers and local ecosystems benefit from improved soil health and water quality, leading to more sustainable agricultural practices.

## **Contribution of the Study**

This study significantly enhances the understanding and management of water hyacinth by systematically reviewing fragmented literature and aligning the findings with the Sustainable Development Goals (SDGs). It provides a comprehensive exploration of the global impacts of water hyacinth, addressing gaps in existing research by examining its environmental, economic, and social dimensions. These insights are essential for policymakers at both global and national levels to develop informed strategies for managing this invasive species.

**Policy Contributions:** The study informs policy-making by highlighting the dual threats of nutrient pollution and water hyacinth proliferation in Lakes Koka and Dembel. It emphasizes the need for coordinated cross-sectoral strategies to safeguard freshwater ecosystems. By offering a detailed analysis of socio-economic and ecological impacts, the study provides critical guidance for developing integrated management policies.

**Methodological Contributions:** The research advances methodological approaches to studying land-use and land-cover (LULC) changes in the Dembel and Koka catchments. Highlighting the cyclical interactions between LULCC and water hyacinth proliferation, it provides a framework for addressing environmental degradation. This methodological rigor serves as a valuable resource for researchers and practitioners aiming to implement sustainable development practices in Ethiopia's Rift Valley and beyond.

**Literature Contributions:** The study bridges gaps in the literature by systematically aligning scattered articles on water hyacinth with broader environmental and socio-economic narratives. It offers new insights into the complex interactions between invasive species and ecosystem dynamics, contributing to a more comprehensive understanding of these challenges.

**Subject Area Contributions:** By exploring water hyacinth's impact on rural livelihoods, the study employs rigorous methodologies and considers socio-economic variables, providing insights that are applicable to regions facing similar challenges. It underscores the importance of understanding socio-economic dynamics to develop effective interventions and management strategies.

**Community Engagement and Resource Utilization:** The study also highlights the socio-economic factors influencing community participation in water hyacinth management. By advocating for diverse participation strategies, it provides a framework for designing more inclusive management projects.

Additionally, it identifies the potential for transforming water hyacinth into a resource, drawing on international best practices to inspire innovative solutions.

In summary, this research offers valuable insights for policymakers, researchers, and local communities, emphasizing the need for integrated management strategies that consider environmental, economic, and social dimensions. It serves as a crucial resource for those working towards sustainable development and effective **invasive** species management.

### **Future Research Areas**

A critical gap identified in this study is the lack of systematic documentation of plant species communities associated with water hyacinth (*Eichhornia crassipes*) in affected water bodies. Future research should prioritize: (1) comprehensive floristic surveys to characterize co-occurring species assemblages, (2) analysis of ecological interactions (e.g., competitive exclusion, facilitation) between water hyacinth and native macrophytes, and (3) assessment of how control measures alter these plant community dynamics. Such investigations would provide essential baseline data for evaluating the cascading impacts of invasion and designing ecologically informed management strategies

Future studies should systematically examine the interplay of ecological and anthropogenic factors driving water hyacinth outbreaks, including nutrient dynamics (e.g., nitrogen and phosphorus loading), climate change effects (e.g., temperature shifts, altered rainfall patterns), and land-use practices. Identifying region-specific thresholds for these variables could enable predictive modeling of infestation risks.

There is a need to design and evaluate hybrid management systems that synergize mechanical removal, targeted biological control (e.g., *Neochetina* weevils or fungal pathogens), and eco-friendly herbicides. Rigorous field trials should assess the long-term efficacy and ecological trade-offs of these combinations, particularly their impacts on non-target species and aquatic ecosystem resilience.

Research must explore scalable methods to repurpose harvested biomass into value-added products, such as biogas, organic fertilizers, or artisanal materials. Techno-economic analyses could identify optimal processing techniques while ensuring economic viability and minimal environmental footprint.

Comprehensive studies are required on quantity to quantify the multidimensional effects of water hyacinth on water quantity, aquatic biodiversity (e.g., native macrophyte displacement), water quality parameters (e.g., dissolved oxygen depletion), and socioeconomic outcomes (e.g., fisheries productivity). Such data would support evidence-based policy prioritization and adaptive management frameworks.

Last but not least, future research should address the development of sustainable technologies, explore long-term ecological impacts, enhance policy frameworks, investigate socio-economic drivers of water hyacinth proliferation, quantify contributions of sediments and nutrient runoff, evaluate water hyacinth management methods, assess community engagement, and explore integrated management strategies for nutrient reduction and institutional collaboration.

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# APPENDICES

## ANNEX 1: LISTS OF TABLES

**Table 1.** Summary of variable used in the models

Variable type	Description	Measurement
Invaded	It is a group variable that indicates the proximity of HH's farmland from the nearest lake within a distance of 300m.	Households adjacent to the lake is invaded =1, otherwise 0.
Dependent variables	Is the outcome variable which is hypothesized to be affected by the invasion of water hyacinth	It is a continuous outcome data
Total Income	It is the sum of return from on-farm, fish sales, and other off-farm activities.	It is measured by ETB <sup>2</sup> in a given year
On-farm income	It is the sum of all crops produced by the household converted into cash based on the average price within the production year.	It is measured by ETB in a given year
Off-farm income	It is the total revenue obtained from different activities other than agriculture	It is measured by ETB in a given year
Income from Fish	It is computed from the amount of fish harvested and selling price	It is measured by ETB in a given year
Tropical Livestock Unit (TLU)	It is computed from the number and type of livestock reared by the respondent	It is measured by converting the livestock's in TLU in a given year.
<b>Explanatory variables</b>		
Age	It is data collected on how old is the respondent	It is continuous data measured in years.
Sex	It is a biological difference between male and female respondents	It is a dummy data, 1= male, 0= female
Education	It is the education level of the respondent	It is continuous data measured in completed years
Land size	It is the farmland ownership of the respondents	It is continuous data measured in hectares.
Experience	It is the respondent's engagement in farming activities	is a continuous data measured in years
Dependency Ratio	It is the proportion of young and retired family member to the work force in the household	It is the ratio data can be less than, greater than, or equals to one
Marital Status	It is to show the marital status of the aged respondents	It is categorical data, 1= Married, 2= Single, 3= Divorced, 4=

<sup>2</sup> ETB is a national currency called as Ethiopian Birr.

Variable type	Description	Measurement
		Widower/widow
Lake dependency	It is to differentiate between households' livelihoods be subject to the lakes or not	It is dummy data, 1= yes, 0= no
Water Knowledge:	H. It is to differentiate between household's knowledge about water hyacinth	It is a dummy data, 1= Yes, 0= no
Lake	It is the lake-based location of respondents	It is dummy data, 1= Dembel, 0= Koka
Dep.*Age	It is the interaction between the household dependency ratio and age of the respondent	It is continuous data measured in the number
Exp.*Edu	It is the interaction between the household head's experience on the farm and education level	It is continuous data measured in number
Land*Lake	the interaction between household land size and lake based location	It is continuous data measured in number

**Table 2.** Characteristics of households by group

Variables	Category	Not Adjacent =166	Adjacent =180	Total =346	chi2	Pr.
Sex of the HH	Female	39	36	75	0.6210	0.431
	Male	124	147	271		
Marital status	Married	136	143	279	0.4816	0.923
	Single	4	6	10		
	Divorced	2	2	4		
	Widowed	24	29	53		
Own any land?	Yes	157	176	333	2.4447	0.118
	No	9	4	13		
Involve in on-farm activities	Yes	116	153	269	11.4116	0.001
	No	50	27	77		
Dependency on Lake?	Yes	135	157	292	2.2800	0.131
	No	31	23	54		

**Table 3.** Grouped household characteristics: two-sample t-test with equal variances

Variables	Group	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	Pr.
Age	Not Adjacent	45.4	1.04576	13.47373	43.2966	0.358
	Adjacent	44.0	1.04620	14.03627	41.9355	
	diff	1.4	1.48169		-1.55288	
Completed education level	Not Adjacent	2.1	0.21986	2.832761	1.67432	0.607
	Adjacent	1.95	0.21522	2.887606	1.52528	
	diff	0.16	0.30791		-0.4472	
Family size	Not Adjacent	4.8	0.14664	1.889422	4.50563	0.100
	Adjacent	5.15	0.15687	2.10473	4.84043	
	diff	-0.35482	0.21568		-0.77905	
Ageless15	Not Adjacent	1.96385	0.12379	1.595036	1.71942	0.293
	Adjacent	2.15	0.12592	1.689517	1.90150	
	diff	-0.18614	0.17700		-0.53429	

Variables	Group	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]		Pr.
Age15_65	Not Adjacent	2.69277	0.09916	1.277619	2.49698	2.88856	0.139
	Adjacent	2.90555	0.10323	1.385065	2.70183	3.10927	
	diff	-0.21278	0.14361		-0.49526	0.06969	
Age>65	Not Adjacent	0.13855	0.02948	0.379898	0.08033	0.19677	0.237
	Adjacent	0.09444	0.02323	0.31173	0.04859	0.14029	
	diff	0.04411	0.03724		-0.02915	0.11736	
Dependency ratio	Not Adjacent	0.95870	0.07085	0.912884	0.81881	1.09860	0.792
	Adjacent	0.93474	0.05778	0.775268	0.82071	1.04877	
	diff	0.02396	0.09083		-0.15469	0.20261	
Land size in ha	Not Adjacent	1.26415	0.07137	0.919578	1.12323	1.40507	0.759
	Adjacent	1.295	0.07049	0.945836	1.15588	1.43411	
	diff	-0.03084	0.10043		-0.22839	0.1667	

**Table 4.** Weighted least square of factors that determined households Livelihood, DID

Variables	DID on Total	DID on-farm	DID on Off-	DID_TLU	DID Fish
Invaded	-822738	-329038	-6952.29	0.002863	-301252
Age	-11858.6	-4136.23	191.767	-0.00457	-5643.47
Education level	-129416	-69129.9	485.2601	0.027241	-20523.4
Land size in ha	-301292	-113019	2939.132	0.163488	-157470
Experience	1328.465	-10724.4	-39.0925	0.000765	9397.64
Lake dependency	176660.3	341851.1	3385.086	-0.22751	-162705
Water H. knowledge	122826.3	193890.8	5989.145	-0.707	-88198.9
Inter DEP*Age	-5689.62	-2986.1	62.49843	0.000589	-1349.22
EXP*Edu.	1780.605	2958.406	10.99544	-0.00137	-1190.65
Land*lake	277104	182891.4	-3418.51	-0.04307	71696.26
_cons	2160934	965360.8	-20605.3	1.109182	899414.1
Number of obs.	346	346	346	346	346
F(10, 335)	2	2.36	3.41	0.97	0.14
Prob. > F	0.0322	0.0104	0.0003	0.4734	0.9991

Source: Own survey 2024

Robust Standard Error in parentheses

\* p=0.1, \*\* p=0.05, \*\*\* p=0.01

**Table 5.** Weighted least square of factors that determined households Livelihood

Variables	Total income	On-farm	Off-farm	TLU	Fish income
Invaded	-748844	-4017.59	3282.715	0.096159	-424733
Age	-11886.1	41.14687	191.3678	0.003282	-8091.29
Education level	-98829.5	-2257.83	1301.467	0.202512	-27884.4
Land size in ha	-318233	-2467.12	4240.307	0.233168	-219647
Experience	1918.129	-367.465	-52.5366	0.039548	13288.94
Lake dependency	144056.3	3931.938	28489.4	0.56511	-230230
Water H. knowledge	41031.41	-4682.94	834.9486	0.091872	-124931
Inter DEP*Age	-4732.36	-62.2568	59.28012	0.006357	-1837.99
EXP*Edu.	1291.547	46.16161	-43.5832	-0.00901	-1712.79
Land*lake	280454.1	6584.876	-1081.97	0.013552	102920
_cons	2285944	32907.49	-25255.1	0.680913	1266670
Number of obs.	346	346	346	346	346

Variables	Total income	On-farm	Off-farm	TLU	Fish income
F(10, 335)	1.92	3.04	6.27	1.96	0.14
Prob. > F	0.0415	0.0011	0.00	0.0364	0.9992

Source: Own survey 2024

Robust Standard Error in parentheses

\* p=0.1, \*\* p=0.05, \*\*\* p=0.01

**Table 6.** Determinants of households' willingness to participate in WH control\_ seemingly unrelated bivariate probit

Variables	Coef.	St.Err.	t-value	p-value	[95% Conf. Interval]	Sig
IB	-.058	.029	-1.97	.049	-.115 0	**
Sex	.493	.209	2.36	.018	.083 .902	**
Education	-.048	.028	-1.71	.088	-.104 .007	*
Land	.013	.093	0.14	.891	-.169 .194	
Water deterioration	-.346	.09	-3.84	0.00	-.523 -.17	***
TLU	-.068	.03	-2.25	.024	-.128 -.009	**
On-farm Income	0	0	0.29	.775	0 0	
Constant	2.279	.381	5.99	0.00	1.533 3.025	***
SB	-.085	.032	-2.63	.008	-.148 -.022	***
Sex	1.295	.58	2.23	.026	.157 2.432	**
Education	-.061	.081	-0.76	.447	-.22 .097	
Land	-.293	.186	-1.58	.115	-.658 .071	
Water deterioration	-.283	.219	-1.29	.195	-.712 .145	
TLU	-.038	.082	-0.47	.642	-.198 .122	
On-farm Income	0	0	0.53	.595	0 0	
Constant	3.316	.861	3.85	0.00	1.628 5.003	***
athrho	20.42	2322.9	0.01	.993	-4532.55 4573.39	
Prob > chi2		0.000	Chi-square			56.420

\*\*\*  $p < .01$ , \*\*  $p < .05$ , \*  $p < .1$

**Table 7.** Land-use Land-cover change matrix for 2014 to 2024 Dembel catchment

<b>Matrix</b>	Bare-	Built-up	Bush and	Agricultural	Forest	Water	Water	Wetlands	<b>Existing</b>
Bare lands	<b>257.35</b>	38.81	0.63	492.92	6.52	8.73	18.77	3.4	<b>827.13</b>
Built-up areas	75.03	<b>1,048.24</b>	1.13	1,835.28	10.47	8.57	4.23	6.89	<b>2,989.84</b>
Bush and Shrub Lands	0.81	309.22	<b>845.75</b>	6,273.45	859.96	0.7	137.81	1,078.94	<b>9,506.64</b>
Agricultural Lands	438.45	5,659.18	16.62	<b>280,577.37</b>	387.97	152.77	443.62	501.45	<b>288,177.43</b>
Forest Areas	-	90.3	78.87	1,305.47	<b>1,818.68</b>	2.39	119.93	1,214.98	<b>4,630.62</b>
Water Body	0.57	5.88	0.07	62.92	84.06	<b>36,087.23</b>	1,702.59	937.38	<b>38,880.70</b>
Water Hyacinth	-	28.85	0	321.51	64.26	553.02	<b>851.58</b>	1,134.88	<b>2,954.10</b>
Wetlands	-	63.34	2.84	629.06	356.09	420.7	919.99	<b>2,064.98</b>	<b>4,457.00</b>
<b>Change Total</b>	<b>772.21</b>	<b>7,243.82</b>	<b>945.91</b>	<b>291,497.98</b>	<b>3,588.01</b>	<b>37,234.11</b>	<b>4,198.52</b>	<b>6,942.90</b>	

**Table 8** Land-use Land-cover change matrix for 2014 to 2024 koka catchment

<b>Matrix</b>	Bare lands	Built-up areas	Bush and Shrub Lands	Agricultural Lands	Forest Areas	Water Body	Water Hyacinth	Wetlands	<b>Existing Total</b>
Bare lands	<b>10.84</b>	22.48	340.32	292.78	106.24	0.00	0.01	6.40	<b>779.07</b>
Built-up areas	31.59	<b>245.20</b>	27.69	1,533.98	45.80	0.11	2.36	48.82	<b>1,935.55</b>
Bush and Shrub Lands	7.94	15.72	<b>46.94</b>	740.84	103.55	0.16		60.77	<b>977.24</b>
Agricultural Lands	534.84	2,302.99	129.95	<b>114,224.18</b>	430.67	73.52	287.87	740.58	<b>118,724.60</b>
Forest Areas	0.00	60.91	30.41	791.30	<b>479.19</b>	0.97	92.87	121.91	<b>1,577.56</b>
Water Body	0.00	42.91		532.67	2.16	<b>9,967.78</b>	2,222.68	179.43	<b>12,948.06</b>
Water Hyacinth	0.00	26.73	7.92	441.77	2.14	1,072.17	<b>1,578.24</b>	111.21	<b>3,240.18</b>
Wetlands	3.96	43.37	6.99	804.53	101.81	5.78	13.86	<b>87.03</b>	<b>1,067.33</b>
<b>Change Total</b>	<b>589.17</b>	<b>2,760.31</b>	<b>590.65</b>	<b>119,362.05</b>	<b>1,271.56</b>	<b>11,120.49</b>	<b>4,199.21</b>	<b>1,356.15</b>	

**Table 9.** The accuracy assessment for LULCC of 1994 for Demel and Koka Lakes basin

Confusion Matrix	Water Body	Water Hyacinth	Wetland	Built-up Area	Cropland	Forests	Bush and Shrub Land	Bare land	Producer's Accuracy	Overall Accuracy	Kappa Statistics
Water Body	56	0	0	0	0	0	0	0	1.00		
Water Hyacinth	0	45	0	0	0	0	0	0	1.00		
Wetland	0	0	44	0	0	0	0	0	1.00		
Built-up Area	0	0	0	55	0	0	0	0	1.00		
Cropland	0	0	0	0	81	0	0	0	1.00		
Forests	0	0	0	0	0	111	0	0	1.00		
Bush and Shrub Land	0	0	0	0	0	1	39	0	0.97		
Bare land	0	0	0	0	0	0	0	35	1.00		
User's Accuracy	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00			
Overall Accuracy										<b>0.996</b>	
Kappa Statistics											<b>0.996</b>

**Table 10.** The accuracy assessment for LULCC of 2004 for Demel and Koka Lakes basin

Confusion Matrix	Water Body	Water Hyacinth	Wetland	Built-up Area	Cropland	Forests	Bush and Shrub Land	Bare land	Producer's Accuracy	Overall Accuracy	Kappa Statistics
Water Body	118	0	0	0	0	0	0	0	<b>1.00</b>		
Water Hyacinth	1	82	0	0	0	0	0	0	<b>0.98</b>		
Wetland	0	0	40	0	0	0	0	0	<b>1.00</b>		
Built-up Area	0	0	0	75	0	0	0	0	<b>1.00</b>		
Cropland	0	0	1	0	188	0	0	0	<b>0.98</b>		
Forests	0	0	1	0	0	111	0	0	<b>1.00</b>		
Bush and Shrub Land	0	0	0	0	0	1	29	0	<b>1.00</b>		
Bare land	0	0	0	0	0	0	0	23	<b>0.88</b>		
User's Accuracy	<b>0.99</b>	<b>1.00</b>	<b>0.95</b>	<b>0.98</b>	<b>1.00</b>	<b>0.99</b>	<b>1.00</b>	<b>1.00</b>			
Overall Accuracy										<b>0.988</b>	
Kappa Statistics											<b>0.986</b>

**Table 11.**The accuracy assessment for LULCC of 2014 for Demel and Koka Lakes basin

Confusion Matrix	Water Body	Water Hyacinth	Wetland	Built-up Area	Cropland	Forests	Bush and Shrub Land	Bare land	Producer's Accuracy	Overall Accuracy	Kappa Statistics
Water Body	94	0	0	0	0	0	0	0	1.00		
Water Hyacinth	0	186	0	0	0	0	0	0	1.00		
Wetland	0	0	42	0	0	0	0	0	1.00		
Built-up Area	0	0	0	98	0	0	0	0	0.98		
Cropland	0	0	1	0	192	0	0	0	0.99		
Forests	0	0	0	0	0	85	0	0	1.00		
Bush and Shrub Land	0	0	0	0	0	0	33	0	1.00		
Bare land	0	0	0	0	0	0	0	52	1.00		
User's Accuracy	1.00	1.00	0.97	1.00	1.00	0.98	1.00	1.00			
Overall Accuracy										0.996	
Kappa Statistics											0.996

**Table 12.** The accuracy assessment for LULCC of 2024 for Demel and Koka Lakes basin

Confusion Matrix	Water Body	Water Hyacinth	Wetland	Built-up Area	Cropland	Forests	Bush and Shrub Land	Bare land	Producer's Accuracy	Overall Accuracy	Kappa Statistics
Water Body	90	0	0	0	0	0	0	0	1.00		
Water Hyacinth	0	157	0	0	0	0	0	0	1.00		
Wetland	0	0	52	0	0	0	0	0	1.00		
Built-up Area	0	0	0	81	0	0	0	0	0.99		
Cropland	0	0	0	0	198	0	0	0	1.00		
Forests	0	0	0	0	0	102	0	0	1.00		
Bush and Shrub Land	0	0	0	0	0	1	25	0	1.00		
Bare land	0	0	0	0	0	0	0	15	1.00		
User's Accuracy	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00			
Overall Accuracy										0.998	
Kappa Statistics											0.997

## Annex 2. Household Questionnaire

### Questionnaire for socio-economic and Livelihood effects of water hyacinth

My name is Assefa Guidna Muleta from Addis Ababa University. I have planned to conduct a study on the Socio-Economic effects of Water Hyacinth around Lake Koka and Hara Dembel in the Central Rift-Valley System. The objective of this study is to evaluate the social, economic and livelihood effects of water hyacinth in some selected Woredas within Lake Koka and Hara Dembel Catchment. I have chosen randomly a list of households from your community. We were able to find your name through a discussion with Woreda Experts and development agents/kebele administration. We will ask some questions on your agricultural practice, land management practices, agricultural production, livestock, livelihood activities and some other information related to water hyacinth and its effect on your day-to-day activities. Hence, this is to kindly request you to answer every question with wisdom, genuine and the facts to the best of your knowledge. Your kind support in providing reliable information is very vital for the success of this study and will be exceedingly appreciated. Your responses and information gathered from you will be kept confidential and only used as input for this study. Your name will not indicated/appear in any public documents and/or publications. Thank you very much for your cooperation.

#### A) Socio-economic and livelihood-related information

##### 1. General information

No.		Code
1.1	Name of Woreda	
1.2	Name of Kebele Admin	
1.3	Name of the village	
1.4	Name of the head of the household	
1.5	Date of data collection	
1.6	Enumerator's name	
1.7	Field supervisor	

##### 2. Demographic and Social Characteristics

No.	Name of the HH member	Age	Sex 1. Male 2. Female	Marital Status 1. Married 2. Single 3. Divorced/Separated 4. Widowed/widow	Completed education level	Occupation 1=Dependent, 2= Student 3=Housewife, 4=Farming, 5=Hired labor, 6=Off-farm activity, 7=Kebele official, 8=other, specify	Relation to the respondent 1=Wife, 2=Child, 3=Grandchild, 4=Brother, 6=Sister, 7=Hired labor, 7=Other
1.							
2.							
3.							

##### 3. Land ownership and use of information

3.1. Does your household own any land? Yes [1] No [ 2]

3.2. How many ha of land does your household own now? \_\_\_\_\_

3.3. If yes, in which location does your household own?

Homestead [1] Dry farmstead (main farmland) [2] Lakeshore [3] Wetland [4] others

3.4. How many plots of land do you own? Please specify their location, area, uses, etc, in the table below

Location of plot	Plot number (start from the nearest)	Total area (in ha)	What are the plots used for? 1. Crop land 2. Grazing land 3. Other(specify)	How did you acquire the land you own? 1. Inherited 2. Rented -in 3. Squatter 4. Land redistribution 5. Share cropped-in	How many years have you cultivated the plot?
1. Homestead	1				
	2				
	3				
2. Dry farmstead	1				
	2				
	3				
3. Lakeshore	1				
	2				
	3				
4. Wetland	1				
	2				
	3				
5. Others (Specify)	1				
	2				
	3				

#### 4. Livestock Ownership

4.1. Does your household own livestock? Yes [ 1] No [ 2]

4.2. If yes, please mention the types and number of livestock you own and the trends of ownership in the following table

S. No	Livestock	Total Number of owned		
		In 2015	In 2010	2000
1	Oxen			
2	Cows			
3	Bulls			
4	Heifer			
5	calves			
6	sheep			
7	Goats			
8	Donkeys			
9	Mules			
10	Chickens			
11	Beehives			
12	Others1 _____			
13	Others2 _____			
14	Others3 _____			

5. Animal Feed/Grazing sources

5.1. What are the main sources of animal feed? Fodder trees and grasses [1] Grazing [2] Hay [3] Straw [4] others \_\_\_\_\_ [5]

5.2. If the major source of your animal feed is grazing, please indicate its location, status and trends in the table below

Location of animal feed sources	The feed status: Abundant 1. Moderate 2. Scarce 3.		
	2015	2010	2000
1. Homestead			
2. Dry communal land			
3. Wetland & lakeshore			
4. Dry land farmsteads			
5, Communal (grazing land)			
6, Others			

6. Livelihood Activities and Income Sources

6.1 Is your household involved in on-farm activities other than agricultural production? Yes [1] No [2]

If yes, the type Activities/Income sources	Is your household involved? 1=Yes 2=No	If your answer is yes, income earned within 12	
		In 2015	In 2010 EC
Crops			
Livestock			
Fishing			
On water transportation using boat			
Tour guider			
Wage labor			
Renting out land			
Other _____			

6.2 Is your household involved in off-and non-farm activities other than agricultural production? Yes [1] No [2]

6.3 If yes, please give the details in the following table

S. No	Activity/ income source	Is your household involved? Yes [1] No [2]	Income earned in the last 12 months	
			In 2015 EC	In 2010 EC
1	Formal/salaried employment			
2	Public works (safety net)			
3	Salaried Employees			
4	Trading in crops			
5	Trading in livestock			
6	Trading in manufactured goods			
7	Sale of charcoal or firewood			
8	Local alcoholic drink preparation			
9	Basket making			
10	Carpentry/house building			
11	Pottery			
12	Blacksmithing			
14	Remittances			
15	Others (specify, if any)			

**A) Knowledge of water hyacinth**

7. Is your livelihood dependent on the Dembel/Koka Lake? Yes [1] No [1]
- 7.1. If yes, for what purpose do you use the water (you can circle more than one)?
- 7.2. Human consumption [1] animals [2] Irrigation [3] Fishing [4] [5] Other (specify)
- 
- 7.3. When did you notice this weed for the first time? Just this year [1] Three years ago [2] Five years ago [3] Ten years ago [4]
- 7.4. Do you know the plant called water hyacinth (emboch)? 1= Yes 2=No  
If yes, please give a response to the following questions
- 7.5. Can you please classify the effect of water hyacinths on local communities adjacent to the lake?  
Low = [1] Moderate= [ 2] Heavy = [3]
- 7.6. In which area does the weed grow? Rangelands [1] Around the village [2] In croplands [3] within the lakes [4] Marshlands/wetlands [5]
- 7.7. Do you know how it came to your area? By livestock [1] by wild animals [2], it just grew itself [3] Brought by foreigners (visitors) [4] don't know [5] Others [6]
- 7.8. To what extent the weed invades the grazing lands? Very dense [1] Medium [2] Sparse [3]
- 7.9. To what extent the weed invades croplands? Very dense [1] Medium [2] Sparse [3]
- 7.10. To what extent the weeds invade the lake and wetland? Very dense [1] Medium [2] sparse [3]

**B. Impact of water hyacinth on crop production**

- 8.1. Have your cultivated plot/s been invaded by water hyacinth? 1=Yes 2=No  
If yes, please give your response to the following questions
- 8.2. How many hectares of your farmland have been invaded by this weed? \_\_\_\_\_ha
- 8.3. To what extent did those grazing invade? Very Dense [1] Dense [2] Medium [3] Sparse [4] V. Sparse [5]
- 8.4. Has this plant affected your agricultural activities? Yes [1] No [2]
- 8.5. If yes, to what extent have plowing activities been affected? V. High [1] High [2] Medium [3] Low [4] V. Low [5]
- 8.6. If yes, to what extent have weeding activities been affected? V. High [1] High [2] Medium [3] Low [4] V. Low [5]
- 8.7. If yes, to what extent have harvesting activities been affected? V. High [1] High [2] Medium [3] Low [4] V. Low [5]
- 8.8. If yes, to what extent threshing activities have been affected? V. High [1] High [2] Medium [3] Low [4] V. Low [5]
- 8.9. If the weed constrains these activities, to what extent has it affected? V. High [1] High [2] Medium [3] Low [4] V. Low [5]
- 8.10. Has the infestation of water hyacinth increased the cost of these activities? Yes [1] No [2]
- 8.11. If the infestation of this weed increases the cost/labor of agricultural activities, please estimate the cost for each agricultural activity

S. No	Agricultural activities	in 2015		In 2010	
		Labor (Man-	Cost	Labor	Cost
1.	Plowing				
2.	Weeding				
3.	Harvesting				
4.	Threshing				
5.	Others				

8.12. Please estimate the yield of crops you produced before and after the infestation of water hyacinth.

S. No	Types of crops	After infestation (in 2015 EC)			Before infestation ( in 2010 EC.)		
		Area	Production	Farm gate	Area	Production	Farm gate price
1	Maize						
2	Sorghum						
3	Potato						
4	Onion						
5	Garlic						
6	Cabbage						
7	Tomato						
8	Spices						
9	Others 1_						
10	Others 2_						
11	Others 3_						

### C. Impact of water hyacinth on livestock production

Effects of water hyacinth on grazing lands

9.13. The availability of animal feed in your location (territory)? Very low [1] Low [2] Moderate [3] High [4] Very high [5]		9.14. Livestock grazing/browsing land area in your (territory)? (In ha)		9.15. No. of palatable grass types (varieties) available for feed? (In No.)		9.16. Did you harvest hay from the field (in your territory)? Yes [1] No [2]		9.17. If you harvested hay, the amount in quintal (kg)?  (Roll/Bond, estimate to kg)		9.18. Could you estimate the quantity of crop residues harvested quintal (kg)?  (Roll/Bond, estimate to kg)	
2015	2010	2015	2010	2015	2010	2015	2010	2015	2010	2015	2010

9.19. In which seasons of the year, water hyacinth infestation reaches peak & very critical for crop production?

Jun, July, & August [1] Sept, Oct & November [2] Dec, Jan, & February [3] March, April & May [4]

9.20. How do you rate estimated crop loss due to water hyacinth?

Sever 50% [1] 75% [2] 100% [3]

Moderate 25% [1] 35% [2] 50% [3]

Scattered 5% [1] 10% [2] 15% [3]

### D. Impact of water hyacinth on fish production

10. In the table below, indicate which months are critical in water hyacinth infestation at your beach/fishing ground?

Water hyacinth and fishing activity in different periods of the	Jan-	Mar-	May-	Jul-	Sep-	Nov-
10.13. Water hyacinth infestation						
10.14. Effect of water hyacinth on fishing activities?						
10.15. Reduction in captured fish species						
10.16. Reduction in fish yield						
10.17. Average price of fish						

In the table below, indicate Fish production and marketing in different periods

Fish type (species)	10.18. The		10.19. The average time		10.20. Avera		10.21. No. of fish	
	2015	2010	2015	2010	2015	2010	2015	2010
Tilapia (ngege)								
African Catfish								
Common carp								
Other 1_____								
Other2-								
Other3-								
Other								

10.22. In the table below, indicate the amount of fish type caught in different period from this part of the lake

Fish type (species) in 2015	Jan-Feb	Mar-	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec
Tilapia (ngege)						
African Catfish						
Common carp						
Other 1_____						
Other 2_____						
Other 3_____						
Other 4_____						

**E. Disease due to water hyacinth**

11. Do you notice any disease due to WH infestation? Yes [1] No [2]  
If yes, respond to the table below

11.1. The frequency of Malaria affected Family members in the HH (in No. per year)		11.2. The frequency of Typhoid affected Family members in the HH (in No. per year)		11.3. The frequency of Cholera affected Family members in the HH (in No. per year)		11.4. The frequency of Itching affected Family members in the HH (in No. per year)		11.5. The frequency of other (specify____) affected Family members in the HH (in No. per year)	
2015	2010	2015	2010	2015	2010	2015	2010	2015	2010

11.6. Do you notice domestic animal death due to WH as a feed? Yes, No

11.7.If yes, which animal do you know is dead as a result? -----

### F. Use of water hyacinth

12. Is Water Hyacinth used as an input in the farm? Yes [ 1] No [2]

12.1. If yes, for what purpose is it used? Compost [1] Mulching [2] Animal Feed [3] Not sure [4]

12.1 The amount of compost produced in the HH (in kg/Qt per year)		12.2 The amount of Mulching used in the HH (in ha per year)		12.3 The amount of Animal feed produced in the HH (in kg/Qt per year)	
In 2015	In 2010	In 2015	In 2010	In 2015	In 2010

12,2 In this area, are there instances when the water hyacinth is harvested for use as raw material for craft work? Yes [1] No [2]

12.3 If yes, list some of the items that are made from the hyacinth:

---

### G. Water source for different purpose

12. Where do you get most of the water used for various purposes?

Sources	12.1. Drinki ng Yes [1] No [2]		12.2. Cooking Yes [1] No [2]		12.3. Livestock watering Yes [1] No [2]		12.4. Bathin g Yes [1] No [2]		12.5. Washing clothes Yes [1] No [2]		12.6 Irrigation Yes [1] No [2]	
	In 2015	In 2010	In 2015	In 2010	In 2015	In 2010	In 2015	In 2010	In 2015	In 2010	In 2015	In 2010
1.Protected												
2. Unprotected												
3. Unprotected												
4.River/ stream												
5. wetland												
6. lake												

### H. Management of Water hyacinth

14.1. How do you rate the ongoing effort with regard to soil and water conservation measures in the upper catchments of the lake for the past 5 years?

Very Low [1] Low [2] Medium [3] High [4] Very high [5]

14.2. How do you rate the level of soil erosion in the area and in the upper catchment of the lake?

Very Low [1] Low [2] Medium [3] High [4] Very high [5]

14.3. Is there a buffer zone (covered by grass, shrubs and trees) established between the wetland and dry land under cultivation? Yes [1] No [2]

14.4. What do you think is/are the causes of the quality deterioration? Rank (1=most important, 2=important 3= moderate 4=least important 5= Not important)

Causes Rank (1-5)

- a) Domestic wastes (liquid and solid) -----
- b) Industrial wastes -----
- c) Agrochemicals -----
- d) Others (specify) -----

14.5. Are there any WH control measures in your locality? Yes [1], No [2]

14.6. If your answer is yes, which control option is very common in your locality?

- a) Chemical [1]
- b) Mechanical (machine and hand removal) [2]
- c) Biological [3]
- d) Integrated [4]

14.7. Which organization in your district do you think is appropriate for the coordination of water hyacinth control and management?

- |                                     |         |        |
|-------------------------------------|---------|--------|
| a) Agriculture development office   | Yes [1] | No [2] |
| b) Environmental protection office  | Yes [1] | No [2] |
| c) Land resources management office | Yes [1] | No [2] |
| d) Water and energy offices         | Yes [1] | No [2] |
| e) District administration          | Yes [1] | No [2] |

**I. Perception of local communities about water hyacinth**

15.1. Invasion of water hyacinth has socio-economic and environmental catastrophes

Strongly agree [1] Agree [2] Slightly agree [3] Disagree [4] Strongly disagree [5]

15.2. I have practically known negative impacts of water hyacinth invasion for the last few years

Strongly agree [1] Agree [2] Slightly agree [3] Disagree [4] Strongly disagree [5]

15.3. I haven't seen any practical challenges of water hyacinth so far

Strongly agree [1] Agree [2] Slightly agree [3] Disagree [4] Strongly disagree [5]

15.4. There is observable water quality deterioration

Strongly agree [1] Agree [2] Slightly agree [3] Disagree [4] Strongly disagree [5]

15.5. If there is water quality deterioration, what are the indicators of the deterioration?

Watercolor change [1] Odor change [1] Other (specify) \_\_\_\_\_

15.6. When did you first noticed changes in water quality deterioration?

This year [1] Two years ago [2] Three years ago [3] Four to Five years ago [4] Longer than 5 years ago

15.7. The water hyacinth has negatively impacted cultural and spiritual values of our community

Strongly agree [1] Agree [2] Slightly agree [3] Disagree [4] Strongly disagree [5]

15.8. The trend and severity of water hyacinth infestation is so worrisome to me  
Strongly agree [1] Agree [2] Slightly agree [3] Disagree [4] Strongly disagree [5]

15.9. Though the mitigation measure is somewhat beyond local effort, I will be part of local mobilization effort  
Strongly agree [1] Agree [2] Slightly agree [3] Disagree [4] Strongly disagree [5]

J. Willingness to restore the lake quality

Consider the following scenario

Dear respondent, this questionnaire is only for PhD research, a dissertation work. It is not related to any governmental organization. So, your information will be kept confidential. Feel free to respond.

You are well aware of the effect of Water hyacinth on social, economic, and environmental as compared to the lake situation five years. So, removing the weed is expected to benefit you through the improvement of ecosystem goods and services.

Hence, if there were a project working on the removal of the weed, yet it requires the participation of the community. The community participation is substantial until the weed is permanently removed from the lake. Thus,

15.10. Are you willing to participate in such activity by contributing labor? Yes [1] No [2]

15.11. If no, do you explain the your reason

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**Bids: willing farmers' participation**

**Bid 1 = 4 Man-day (MD) / month**

15.12. If yes in question 15.10, are you willing to contribute 4 MD / month? Yes [1] No [2]

15.13. If yes in Q 15.12, are you willing to contribute 6 MD / month? Yes [1] No [2]

15.14. If no in the Q 15.12, the amount of MD you are willing to contribute per month \_\_\_\_\_

15.15. If no in Q 15.12, are you willing to contribute 2 MD / month Yes [1] No [2]

15.16. If no in the Q 15.15, the amount of MD you are willing to contribute per month \_\_\_\_\_

**Bid 2 = 6 Man-day (MD) / month**

15.17. If yes in question 15.10, are you willing to contribute 6 MD / month? Yes [1] No [2]

15.18. If yes in Q 15.17, are you willing to contribute 9 MD / month? Yes [1] No [2]

15.19. If no, in Q 15.18 the amount of MD you are willing to contribute per month \_\_\_\_\_

15.20. If no in Q 15.17, are you willing to contribute 3 MD / month? Yes [1] No [2]

15.21. If no in the Q 15.20, the amount of MD you are willing to contribute per month \_\_\_\_\_

**Bid 3 = 8 Man-day (MD) / month**

15.22. If yes in question 15.10, are you willing to contribute 8 MD / month? Yes [1] No [2]

15.23. If yes in Q 15.22, are you willing to contribute 12 MD / month? Yes [1] No [2]

15.24. If no in the Q 15.23, the amount of MD you are willing to contribute per month \_\_\_\_\_

15.25. If no in Q 15.22, are you willing to contribute 4 MD / month Yes [1] No [2]

15.26. If no in the Q 15.25, the amount of MD you are willing to contribute per month \_\_\_\_\_

**Bid 4 = 12 Man-day (MD) / month**

15.27. If yes in question 15.10, are you willing to contribute 12 MD / month? Yes [1] No [2]

15.28. If yes in Q 15.27, are you willing to contribute 18 MD / month? Yes [1] No [2]

15.29. If no in the Q 15.28. the amount of MD you are willing to contribute per month \_\_\_\_\_

15.30. If no in Q 15.27, are you willing to contribute 6 MD / month Yes [1] No [2]

15.31. If no in the Q 15.30, the amount of MD you are willing to contribute per month \_\_\_\_\_