



JIMMA UNIVERSITY
COLLEGE OF SOCIAL SCIENCES AND HUMANITIES
DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

THE EXPANSION OF *EICHHORNIA CRASSIPES* AND ITS IMPACT ON THE
LIVELIHOODS: A CASE OF LAKE DAMBAL, OROMIYA, ETHIOPIA

BY: GUTEMA GODANA WAKEYO

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment
of the Requirements for the Degree of Master of Science in Geographic Information System and
Remote Sensing

December, 2021
Jimma, Ethiopia

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Research Title: **The Expansion of *Eichhornia crassipes* and Its Impact on the Livelihoods: A Case of Lake Dambal, Oromiya, Ethiopia**

I, Gutema Godana, declare that this thesis work has not been presented anywhere else before and it is my original work.

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ABBREVIATION AND ACRONYM

ATJK	Adami Tullu Jido Kombolcha
CABI	Centre for Agriculture and Bioscience International
CRV	Central Rift Valley
CSA	Central Statistical Agency
EBI	Ethiopian Biodiversity Institute
ENVI	Environmental for Visualizing Image
EPPO	European and Mediterranean Plant Protection Organization
ESRI	Environmental System and Research Institute
GIS	Geographic Information Science
KIA	Kappa Index of Agreement
LVEMP	Lake Victoria Environmental Management Programme
MSI	Multi-Spectral Instrument
ONRS	Oromia National Regional State
SNNPR	South Nation Nationalities and People Regional State
SSIU	Small Scale Irrigation Users
SVM	Support Vector Machine
UNEP	United Nation Environmental Program
UNWDR	Uganda National Water Development Report
USGS	United State Geological Survey
WSSF	Wonji Shoa Sugar Factory

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ABSTRACT

The major problem of fresh water bodies in the tropical and sub-tropical region is the growth of Eichhornia crassipes. The spread of Eichhornia crassipes on Lake Dambal impedes the livelihoods of society that depends on it. The aim of the study is the expansion of Eichhornia crassipes and its impact on the livelihoods with the specific objectives of mapping the expansion of Eichhornia crassipes, analyzing the extent of Eichhornia crassipes expansion from 2017 to 2021, and examining its impacts on the livelihoods of societies. Four hundred and fourteen (414) respondents, were selected from all peasant associations around Lake Dambal using a simple random sampling technique. Questionnaires and a Geographical positioning system were the instruments used for data collection. The sentinel-2 satellite images were obtained from USGS & Copernicus Hub Open Access. It was pre-processed and classified by QGIS and eCognition software respectively. Social data were analyzed by SPSS software and the results were presented in frequency counts, percentages, Chi-square (χ^2), and Analysis of Variance (ANOVA). The results show that the image of each year was classified into five major classes: water, irrigated land, Eichhornia crassipes, wetland, and Grazing land (includes settlement & Iceland). In the year 2017, Eichhornia crassipes coverage was 32.51 ha, 0.06% of the total area of 52,285.4 ha. In 2019, Eichhornia crassipes coverage was increased to 64.92 ha, which is 0.12% of the total area. In 2021, Eichhornia crassipes expansion increased to 317.69 ha which is 0.61% of the study area. Their results show that Eichhornia crassipes expansion increased in extent from 2017 to 2021 by +285.18 ha (+0.55%). The Eichhornia crassipes expansion was affecting the livelihoods of the society. It was used for animal fodder in the study area. However, it affected animal health and milk production. The expansion of Eichhornia crassipes around Lake Dambal is increasing quickly in extent more than +285.18 ha (+0.55%). Therefore, all concerning bodies should have to take appropriate action to control the expansion of the weed over the lake and lands around it.

Key words: *Eichhornia crassipes; Weed invasion; Change detection; Eichhornia crassipes impact*

CHAPTER ONE

INTRODUCTION

1.1. Background

Fresh water bodies constitute a vital component of a wide variety of living environments as an integral water resource base in many human societies in the world. They have been regarded as key strategic resources essential for sustaining human livelihood, promoting economic development, and maintaining the environment (UNWDR, 2005).

The major problem in the water bodies especially in tropics and sub-tropics is the growing of aquatic weed *Eichhornia crassipes*, which is originated from the Amazon basin and has expanded quickly in many parts of the world (Barret and Forno, 1982; Julien *et al.*, 1999; Julien *et al.*, 2001; Piyaboon *et al.* 2016). It is a free-floating aquatic weed that grows in water bodies like Lakes and a perennial monocotyledonous crop that belongs to the Pontederiaceae family. *Eichhornia crassipes* is an invasive aquatic plant associated with a variety of ecological and economic effects on freshwater ecosystems (Chunkao *et al.*, 2012). It causes conservation challenges and socioeconomic problems due to its fast growth and lateral expansion. This weed poses major problems to stream flow, navigation, and recreational activities and disrupts aquatic systems (Teñlez *et al.*, 2008).

In Africa, *Eichhornia crassipes* was first reported in Egypt between 1879 and 1893 (FAO, 2000). It is considered one of the most notorious weed species in tropical West Africa. According to UNEP (2013), *Eichhornia crassipes* is the most widespread and damaging aquatic species identified as a toxic weed. The several water bodies invaded by *Eichhornia crassipes* in African continents include Ologe Lagoon, Agbara and Badagry Rivers (all in Nigeria), River Niger (Mali), River Zambezi (Zambia), and the Nile River (Egypt) (Borokini & Babalola, 2012; Dagno *et al.*, 2012; Patel, 2012). The dangers caused by *Eichhornia crassipes* such as biodiversity, deteriorating water quality, economic development, and human well-being, are not easily managed and are difficult to reverse. So, it is defined as the most troublesome weed worldwide as well (Ndimele *et al.* 2011). Sometimes, it brings about a decline of dissolved oxygen in water bodies causing the death of many fish and other aquatic life (Teñlez *et al.*, 2008). According to Navarro and Phiri (2000), *Eichhornia crassipes* have negative impacts on the socio-economic

activities of the communities. Ecologically, benthic and littoral diversity is reduced (Masifwa *et al.*, 2001; Toft *et al.*, 2003; Midgley *et al.*, 2006).

In Ethiopia, *Eichhornia crassipes* was officially first found in 1965 in Qoqa Lake and the Awash River (Stroud, 1994; Wondie, 2013; Firehun *et al.*, 2014). *Eichhornia crassipes* infestation in Ethiopia has been manifested on a large scale in many water bodies of the country. The introduction and rapid spread of this weed in the Awash River Basin (Qoqa artificial Dam), Abbay River Basin (Lake Tana, Blue Nile), Baro-Akobo River Basin (Sobate, Baro, Gillo and Pibor rivers), and Rift Valley Basins System (Lake Ellan, Lake Abaya), has created problems for the water as a resource (Stroud, 1994; Rezene, 2005; Taye *et al.*, 2009). The major problems created by *Eichhornia crassipes* include: hindrance to water transport, disrupting hydro-electric operations, blockage of canals and rivers, causing flooding and human health problem, increased evapotranspiration, interference with fishing, irrigation, navigation, livestock watering, and reduction of biodiversity (Hailu *et al.*, 2004; Taye *et al.*, 2009).

The livelihoods of people in Ethiopia mainly depend on the ecosystem goods and services such as economic dependences, social well beings, and livelihoods to those who found around the particular ecosystem like Lake Ecosystem. Lake Ecosystem has played a great role to support the livelihoods of the people found around Lakes (EFTEC, 2005). Lake Dambal provides ecosystem goods and services to different users such as Horticulture Company, small-scale irrigation schemes, production of fishes, drinking water for livestock, recreational activities, and others. Lake Dambal has still embraced the intrinsic value and aesthetic quality of a wetland, including its functions as a shelter for a rich diversity of plants, aquatic birds, and fish and ecological functions like filtering pollutants and sediments, buffering against wind and storm (Seyoum, 2016). Therefore, Lake Dambal is the main source of income to various groups of communities. But the expansion of *Eichhornia crassipes* on Lake Dambal is worsening and posing various threats to the livelihoods of the local communities. Hence, analyzing the extent of *Eichhornia crassipes* expansion, mapping the expansion of *Eichhornia crassipes*, and assessing its effects on livelihoods will be important for lake management and its life sustainability.

1.2. Statement of the Problem

Eichhornia crassipes displaces native aquatic plants and animal communities. It causes substantial economic hardship and interferes with water uses. One of the freshwater Lakes infested by *Eichhornia crassipes* is Lake Dambal, which is the third-largest of the seven Ethiopian Rift Valley Lakes. This Lake provides ecosystem services with a significant contribution to the livelihoods of the community. The Lake provides water for irrigation, domestic, and supplying fish to the market. As described by Seyoum (2016), the mean minimum and a maximum number of fish caught per year from Lake Dambal were 504 and 16,800 kg respectively. The total water consumed for irrigation and domestics from Lake Dambal was 197,844,647.3 m³ per year (Girma, 2015) and 1.26 x 10⁶ m³ per year (Goshime *et al.*, 2019) respectively. It supports large-scale export-oriented irrigated floriculture and many small-scale irrigation schemes.

Eichhornia crassipes have been the worst invasive weeds about its negative impacts on economic and social structures (Bhattacharya *et al.*, 2015). The invasion of the weed has affected the potential of the Lake to support economic development and local communities' livelihoods. The spread of *Eichhornia crassipes* on Lake Dambal impedes the livelihoods of society like fishing, irrigation, boat transportation, etc. *Eichhornia crassipes* is clogging major waterways and creating associated problems with water supply, irrigation, and drainage. And it reduces the availability of water by increasing evapotranspiration and reducing water quality through introducing particulate matter. The dense growth of the *Eichhornia crassipes* prevents boats from reaching shore, disrupts aquatic life such as fish and phytoplankton, and causes siltation and the gradual drying up of this water body.

Studies show that in Ethiopian rift valley lakes, *Eichhornia crassipes* was not observed on Lake Dambal (Firehun *et al.*, 2007). According to this previous study, from water bodies found in the Ethiopian rift valley; only Lake Qoqa, Awash River, and Lake Ellen have been influenced by *Eichhornia crassipes* and other water bodies like Lake Dambal was free of *Eichhornia crassipes* invasion. But *Eichhornia crassipes* has been observed on Lake Dambal and

has created various problems on the livelihoods of the societies. Studies have been conducted on the expansion of *Eichhornia crassipes* detection using Landsat 8 satellite image (30 m x 30 m spatial resolution) in Ethiopia (Firehun *et al.*, 2007; Firehun, 2017; Tewachew *et al.*, 2020). However, sentinel_2 satellite image was used for the expansion of *Eichhornia crassipes* on Lake Dambal & it is surrounding.

1.3. Objective

1.3.1. General Objective

The aim of the study is to analyze the expansion of *Eichhornia crassipes* and its impact on the livelihoods: a case of Lake Dambal, Oromiya, Ethiopia.

1.3.2. Specific Objectives

The specific objectives of the study are

- to map the expansion of *Eichhornia crassipes*;
- to analyze the extent of *Eichhornia crassipes* invasion from 2017 to 2021; and
- to examine the effects of *Eichhornia crassipes* on livelihoods.

1.4. Research Questions

The study findings provided answers to these questions:

- Is *Eichhornia crassipes* changing spatiotemporally on the Lake?
- To what extent *Eichhornia crassipes* is spreading over the Lake between 2017 up to 2021?
- What are the impacts of *Eichhornia crassipes* on the livelihoods?

1.5. Significance of the Study

The thesis was focused on the expansion of *Eichhornia crassipes* using geospatial techniques and its impact on the livelihoods of the societies. And such a study is providing baseline data for decision-makers and water resource managers to understand the spatiotemporal dynamics of the weed and have an implication to formulate and implement effective strategies for better monitoring and intervention activities. The findings of the study will also be useful for future Lake resource planning and water quality monitoring in the country. The findings of the study

could also be used as a source of information for those researchers who intend to do similar or related research.

1.6. Scope and Limitations of the Study

The study was focused on the expansion of *Eichhornia crassipes* from the year 2017 to 2021 (4 years) and its impact on livelihoods a case of Lake Dambal. Geographically the study was delimited to Lake Dambal situated between Dugda, Adami Tullu Jido Kombolcha (ATJK), and Ziway Dugda districts in East Shawa.

The study has relied on Sentinel_2 satellite images and data from a selected sample of community members. Lack of high-resolution satellite images like Quick bird might affect the finding of the study. And some of the respondents were not free to share information regarding *Eichhornia crassipes* due to the political situation of the country. Although the effects of *Eichhornia crassipes* on livelihoods might be varying from one respondent to the others (subjective response). Therefore, interpretation of the data was done based upon the information gathered from the sample respondents and the findings of the study were generalized to the target population.

1.7. Organization of the Study

The study includes five chapters. Each chapter contains its sub-titles. Chapter one includes the introduction about *Eichhornia crassipes* and its impacts. The statement of problem, objectives, research questions, the significance of the study, and scope & limitation of the study were included under this chapter. Chapter two is the literature review describing the previous studies related to the area of interest. Chapter three is about the materials and methods. This chapter includes sub-titles: description of the study area and methodology. Chapter four contains the results and discussions parts. In this chapter, the finding of the study is described and discussed. Chapter five includes conclusions and recommendations of the study. Finally, the reference materials used are described.

CHAPTER TWO

LITERATURE REVIEW

2.1. Biology of *Eichhornia crassipes*

Eichhornia crassipes is a perennial, herbaceous and aquatic plant species of the family Pontederiaceae which reproduces both sexually and asexually, this means by aiding the modes to proliferate. During moderate climates, *Eichhornia crassipes* flowers grow throughout the year and can generate sufficient seeds to produce an abundance of seeds (USFWS, 2015).

The genus *Eichhornia* contains several other species, which are aquatic, but only *Eichhornia crassipes* have become a serious weed (Coetzee *et al.*, 2009b). The leaves of *Eichhornia crassipes* comprise smooth, glossy, circular to the kidney-shaped lamina and a swollen, spongy petiole (Figure 1). The petiole contains air, causing plants to float on the water surface. Population increase in *Eichhornia crassipes* plant is through ramet (daughter plant) vegetation from axillary buds (stolons) of elongated internodes. As the ramets develop roots, the axillary buds or stolons disintegrate and split from the original plant. Under favorable conditions, these daughter plants through its spread, thus aid in the swift increase in *Eichhornia crassipes* population in an interval of 1 to 3 weeks (EPPO, 2008).

The *Eichhornia crassipes* plant produces fruits or seeds at a temperature of 22.5°C - 35°C and a humidity of 90% and the growth of these seeds are influenced by significant light, and a changing high and low temperatures of 5°C - 40°C. If the plant is introduced in near-freezing temperature for 2 to 4 weeks, its population will be reduced greatly (USFWS, 2015). Bisexual flowers are bluish-purple with a yellow center and are produced on a single spike up to 60 cm in length (Julien *et al.*, 1999). The flowers can be self-fertilized. The roots are long, fibrous, and feathery.



Figure 1: Morphology of *Eichhornia crassipes* (USFWS, 2015).

Eichhornia crassipes seeds germinate in backwater areas, in ditches and channels, and other moist habitats. The seedlings develop into plants with their leaves and root systems within 40 days after germination (Barrett, 1980). After some time, the plants get detached from the mud and become free-floating and then they multiply vegetative and form floating mats (Rao, 1988).

Rapid vegetative growth through off-sets is the main secret of a quick build-up of *Eichhornia crassipes* into blankets of dense, tough mats. Holm *et al.* (1991) reported that two-parent plants were surrounded by 300 off-springs within 23 days and even 1200 after four months. The floating mats of *Eichhornia crassipes* are often strong enough to allow it to walk over them and to stop boats and ships.

2.2. Trends of *Eichhornia crassipes* Distribution

2.2.1. Global Distribution

Eichhornia crassipes have been spread from South America (Amazon basin) to other parts of the World since the 1800s (Navarro and Phiri, 2000). The mechanism of spreading of *Eichhornia crassipes* from one area to another area is different; distributed intentionally or unintentionally by humans (Penfound and Earle, 1948; Global Invasive Species Database, 2006; Dagno *et al.*, 2012). The invasive weed has spread from continent to continent; from one country to another country; from one water body to another water body mainly by man, legs of birds, and shared and common rivers and watersheds. But humans are the main agent of *Eichhornia crassipes* spreading (Van Driesche *et al.*, 2002; Cilliers *et al.*, 2003; Tellez *et al.*, 2008). To date, *Eichhornia crassipes* have spread throughout Southeast Asia, the South-eastern United States, central and western Africa, Central America, and the Iberian Peninsula in southwestern Europe (Bartodziej and Weymouth, 1995; Martinez-Jimenez & Gomez-Balandra, 2007; Aguiar and

Ferreira, 2013). Since the end of the nineteenth century, *Eichhornia crassipes* has been taken from its origin to all parts of the world as ornamental and botanical gardens plant (CABI, 2015).

These weeds are readily distributed by streams, winds, fishing nets and water craft (Julien *et al.*, 1999). It has also been spread through the dispersal of seeds. As the seeds are released directly into the water (Barrett, 1980), they can also be easily transported by vehicles, boats or pedestrians passing through infested areas (Julien *et al.*, 2001). But where the weeds produce seeds, these may cause a new outbreak of *Eichhornia crassipes* even after a certain site is cleared of an initial infestation (Gopal, 1987).

But things got out of control: the *Eichhornia crassipes* was like a tiger let out of its cage (Tegene and Ayele, 2014). Later, *Eichhornia crassipes* has found its way into rivers, Lakes, dams, reservoirs, irrigation, and drainage structures throughout the tropics and the sub-tropics and became an invasive weed (CABI, 2015).

Under favorable growing conditions and environmental circumstances, some estimates suggest that *Eichhornia crassipes* can double its biomass through asexual reproduction in two weeks. Within eight months, ten *Eichhornia crassipes* plants can reproduce 655,360 plants that can cover approximately half a hectare of the surface area (Gunnarsson and Petersen, 2007). Wilson *et al.* (2005) indicated that nutrient concentration and increased Land Surface Temperatures (LST) are two of the most important aspects, influencing the growth and reproduction of *Eichhornia crassipes* species in open water bodies. So far, *Eichhornia crassipes* have spread to most of the tropical freshwater bodies throughout the world and have been described as one of the most invasive aquatic weeds on the planet (Cook, 1989; Ndimele *et al.*, 2011; Havel *et al.*, 2015).

In Europe, *Eichhornia crassipes* is established in the Azores (France) and Corsica (Italy), and casual records are known from Belgium, the Czech Republic, Hungary, the Netherlands, and Romania (EEA, 2012). Greca *et al.* (2009) indicated that *Eichhornia crassipes* is a threat in Spain and Portugal. It was used to be a popular water plant widely sold in home garden shops. However, recently *Eichhornia crassipes* have been put on the European Union list of invasive species and may no longer be sold or imported. In Asia, *Eichhornia crassipes* is widespread on freshwater wetlands of the Mekong Delta, especially in standing water (MWBP/RSCP, 2006).

Biswas *et al.*, (2007) reported that *Eichhornia crassipes* have been detected in the Sundarbans mangrove forest of Bangladesh and have caused heavy siltation in the wetlands of the Kaziranga National Park, India. As in many other countries, *Eichhornia crassipes* has caused many economic, social, and environmental problems in southern China (Choo *et al.*, 2006).

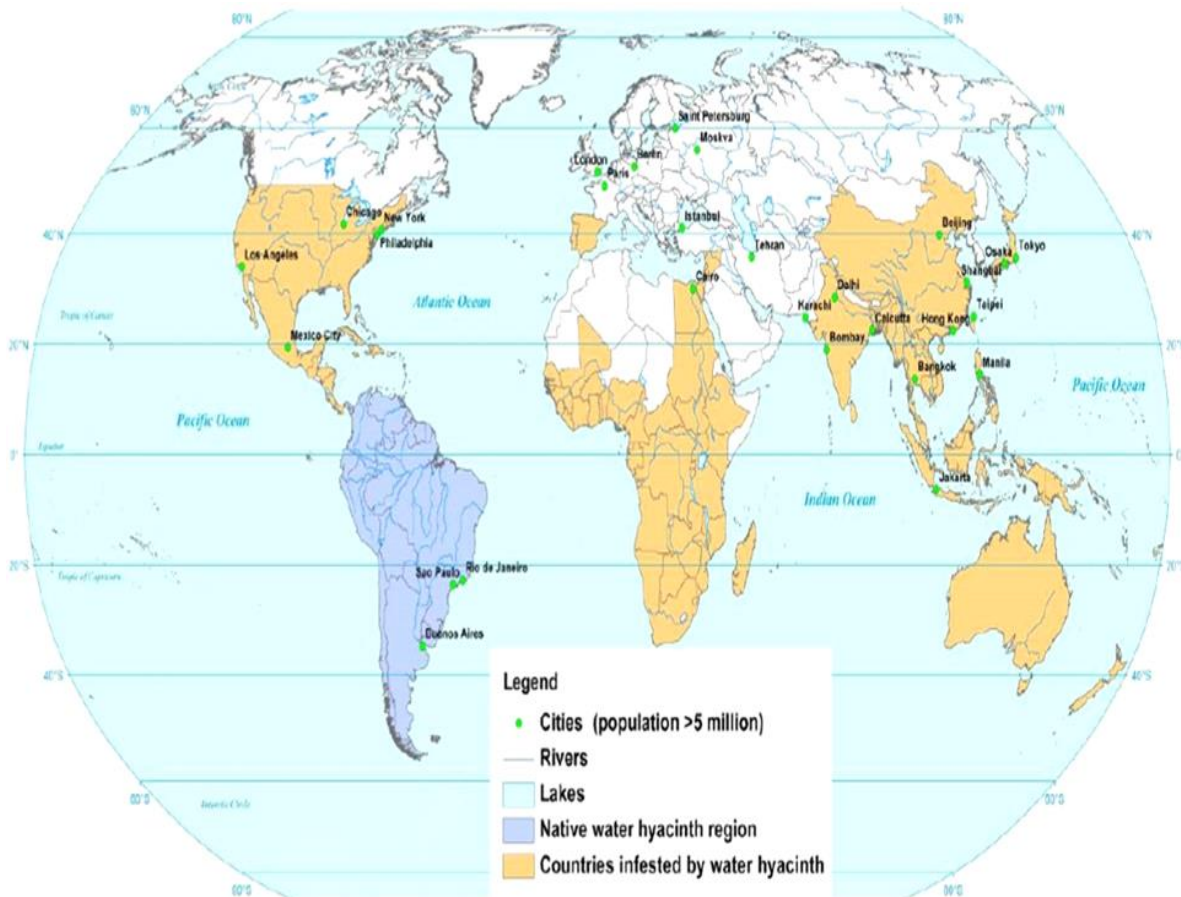


Figure 2: Global distribution of invasive *Eichhornia crassipes* (Tellez et al., 2008)

2.2.2. Distribution of *Eichhornia crassipes* in Africa

Eichhornia crassipes was introduced into Africa from South America in the early 1900s (Mitchell, 1985; Gopal, 1987; FAO, 2000). In the period of 1975–85, *Eichhornia crassipes* has been a problem in Egypt (Cilliers, 1991; Navarro and Phiri, 2000). In South Africa, it was observed in 1910 and became a problem in 1983. In Zimbabwe, it was observed in 1937, Mozambique (In Comati River) in 1946, Zambia River in 1956, Rwanda and Burundi in the late 1950s, Tanzania (Pangri River) and Zambia (Kafue River) in the 1960s, Malawi (Shire River) in 1968, Kenya (Lake Naivasha) in 1982–83, Uganda (Kyoga Lake) in 1988–89, Victoria lake in

1989–90, Malawi (Nyasa Lake) in 1996, Sudan (discovered near Bor town) in 1954, Nigeria in 1984, and Lake Tanganyika in 1997 (Olckers, 2000; Coetzee *et al.*, 2007; Hill and Coetzee, 2008; Hill and Jernelov, 2017; Navarro and Phiri, 2000). Therefore, in different parts of African continents, *Eichhornia crassipes* became a problematical weed Since the 1950s. In the East African region, the weed was first noticed almost simultaneously in Uganda, Tanzania, and Kenya in 1987 (Ogwang and Molo, 1999). The sources of distribution of *Eichhornia crassipes* have been different in some parts of Africa.

In Egypt, it has been distributed as an ornamental plant for Public gardens (Cairo and Nile Delta) between the 1890s and 1900s (Simpson, 1932; Gopal, 1987). In Sudan, the source of the weed was the Congo River where the infestation was in 1952. In Nigeria, the weed came from Benin (Navarro and Phiri, 2000).

Eichhornia crassipes occur in most of the wetlands of Africa and pose serious social, economic, and environmental problems for millions of people and therefore, add constraints on the development of the nation (Howard and Matindi, 2003). The distribution status of the weed in Africa is shown in Table 1.

Table 1: *Eichhornia crassipes* distribution in Africa (CABI, 2015)

Country	Distribution status	References
Angola	Restricted distribution	Gopal (1987)
Benin	Restricted distribution	EPPO (2014) & van Thielen (1993)
Botswana	Present	Gopal (1987)
Burkina Faso	Present	EPPO (2014)
Burundi	Present	Moorhouse <i>et al.</i> (2001) & EPPO (2014)
Cameroon	Present	EPPO (2014)
Central African Republic	Restricted distribution	Gopal (1987)
Congo	Widespread	Gopal (1987) & EPPO (2014)
Congo Democratic Republic	Widespread	Gopal (1987) & EPPO (2014)
Côte d'Ivoire	Restricted distribution	Harley (1993) & EPPO (2014)
Egypt	Widespread	Fayad <i>et al.</i> (2001) & EPPO (2014)
Equatorial Guinea	Present	EPPO (2014)
Ethiopia	Restricted distribution	Gopal (1987) & EPPO (2014)
Gabon	Present	EPPO (2014)
Ghana	Restricted distribution	EPPO (2014) & de Graft-Johnson (1993)
Guinea	Present	EPPO (2014)
Guinea-Bissau	Present	EPPO (2014)
Kenya	Widespread	Owiti (1990), Mailu (2001) & IPPC-Secretariat
Liberia	Present	EPPO (2014)
Madagascar	Widespread	Binggeli (2003) & EPPO (2014)
Malawi	Widespread	Harley (1993), Phiri <i>et al.</i> (2001) & EPPO (2014)
Mali	Restricted distribution	Lomer (1995)
Mauritius	Present	Gopal (1987) & EPPO (2014)
Morocco	Present	EPPO (2014)
Mozambique	Restricted distribution	Gopal (1987) & EPPO (2014)
Niger	Restricted distribution	Akinyemiju (1987) & Lomer (1995)
Nigeria	Restricted distribution	Akinyemiju (1987) & EPPO (2014)
Réunion	Present	Gopal (1987) & EPPO (2014)
Rodriguez Island	Present	Royal Botanic Gardens Kew (2012)
Rwanda	Widespread	Harley (1993) & EPPO (2014)
Senegal	Restricted distribution	Gopal (1987) & EPPO (2014)
Seychelles	Present	Royal Botanic Gardens Kew (2012)
Sierra Leone	Present	EPPO (2014)
South Africa	Widespread	Jones (2001) & EPPO (2014)
Sudan	Widespread	EPPO (2014)
Swaziland	Present	EPPO (2014)
Tanzania	Widespread	Mallya <i>et al.</i> (2001) & EPPO (2014)
Zanzibar	Restricted distribution	Gopal (1987)
Togo	Present	EPPO (2014)

2.2.3. Distribution of *Eichhornia crassipes* in Ethiopia

In Ethiopia, *Eichhornia crassipes* was officially first described in Qoqa Lake and the Awash River (Stroud, 1994). *Eichhornia crassipes* infestation in Ethiopia has been manifested on a large scale in many water bodies of the country. An exploratory survey assessed the occurrence of *Eichhornia crassipes* on the different water bodies of Ethiopia. Reports indicated there was *Eichhornia crassipes* infestation especially in Baro, Gillo, and Akobo Rivers in Western Ethiopia (Rezene, 2005). However, sporadic visits, including some clean-up attempts have been made during 1959, 1968, 1979, and 1988 (Firehun *et al.*, 2007).

Recently, *Eichhornia crassipes* infestation has also been observed in Lake Tana and the Wonji-Shoa sugar factory. According to Firehun *et al.* (2007), *Eichhornia crassipes* have become a major invasive alien weed in the Rift Valley of Ethiopia having successfully established and invaded the different water bodies. The field assessment on the occurrence and severity of *Eichhornia crassipes* infestation showed that the weed prevails in most of the Rift Valley Lakes, canals, reservoirs, irrigation water supplies, and drainage structures with different magnitudes of infestation. However, Lake Bishoftu, Lake Cheleleka, Lake Dambal, Lake Langano, Lake Awassa, Lake Chamo and Lake Beseka were confirmed to be free of the *Eichhornia crassipes* problem (Firehun *et al.*, 2007). But later, new records of *Eichhornia crassipes* infestation on Lake Dambal was observed.

2.3. Causes of Rapid *Eichhornia crassipes* Expansion

Optimum growth of *Eichhornia crassipes* occurs in still or slow-moving fresh water under conditions of high relative humidity, long sun exposure, the water temperature of 28-30 °C, and abundant availability of nitrogen, phosphorous, and potassium (Reddy *et al.*, 1991; Gaikwad and Gavande, 2017). Plants can, however, tolerate a wide range of growth conditions and weather extremes. The plants can also withstand frost, although prolonged cold weather may kill them while the seeds remain viable (Wright and Purcell, 1995).

The favorable habitat or environment for the growth of *Eichhornia crassipes* ranges from tropical desert to subtropical or warm temperate desert to rainforest zones. The rapid reproduction rate of *Eichhornia crassipes* is because of two major conditions: climatic and water body conditions (Gaikwad and Gavande, 2017). Temperature, sunlight shading, salinity,

disturbance, eutrophication, pH, and reproduction systems are the main determinant factors for the optimum growth of *Eichhornia crassipes* (Gaikwad and Gavande, 2017).

The most favorable conditions are quiescent water, shallow water depth (< 6 m), bed surface covered with deposited sediment rich in organic matters, and availability of vital elements such as nitrogen and phosphorous in nutrients (Makhanu, 1997). Sunlight is important for photosynthesis because the nutrient uptake from the water by its root is not enough for the overall optimum growth of the invasive weed. The optimum salinity condition for *Eichhornia crassipes* is < 2% salt in the water.

Table 2: Optimum conditions for *Eichhornia crassipes* growth

Parameter	Optimum Value	Authors
Lake depth	< 6 m	Makhanu (1997)
Temperature	28 – 30°C	Gaikwad and Gavande (2017)
Salinity	< 2%	Gaikwad and Gavande (2017)
Nitrate (N)	5.5 – 20 mg/L	Gaikwad and Gavande (2017); Khan and Ansari (2005)
Phosphate (P)	1.66 – 3 mg/L	Gaikwad and Gavande (2017)
Potassium (K)	Up to 53 mg/L	Gaikwad and Gavande (2017)
pH	6.5 – 8.5	Gaikwad and Gavande (2017)

2.4. Effects of *Eichhornia crassipes* on Livelihoods

Eichhornia crassipes is one of many aquatic invasive plant species worldwide that causes losses in biodiversity and changes in ecosystems; and socio-economic impacts by negatively affecting activities such as agriculture, forestry, fisheries, and power generation (Hill and Coetzee, 2008). The introduction and spread of *Eichhornia crassipes* in many countries continue to threaten the socio-economic and livelihood of their populations (Mailu, 2001; Kateregga and Sterner, 2007; Rema, 2016).

According to Firehun *et al.* (2007), *Eichhornia crassipes* caused a range of detrimental effects include excessive evapotranspiration, restricting water flow, human health problems, and increased plantation cost. *Eichhornia crassipes* has caused a loss of aquatic biodiversity, reductions in water quality & quantity, and threatens the livelihoods of the local communities by

disrupting their fishing and other socio-economic activities (Gashamura, 2009; Seburanga *et al.*, 2014), substratum and habitat for colonization of macroinvertebrates. Therefore, the presence of aquatic alien species in freshwater systems is a great concern to environmentalists, farmers, fishermen, boat navigators, water resource managers, catchment managers, and hydrologists. Besides, invasive species proliferation is a substantial global change phenomenon that increasingly affects aquatic life, ecosystem functioning and productivity, ecological and hydrological processes, and human livelihoods (Schneider and Geoghegan, 2006; Burgiel and Muir, 2010).

2.4.1. Effects of *Eichhornia crassipes* on Water Quantity

Eichhornia crassipes caused wastage of water through excessive evapotranspiration (Firehun *et al.*, 2007). This impact of the weed was reported by different scholars in different countries (Allen *et al.*, 1997; Howard and Matindi, 2003). Allen *et al.* (1997) also indicated this effect can cause loss up to 13 times from that of a free water surface with a minimum rate of 2.5 times. Some report also indicated that *Eichhornia crassipes* leads to excessive loss of water through evapotranspiration up to 1.8 times more than surface water free of *Eichhornia crassipes* infestation (Ezama, 2019).

2.4.2. Effects of *Eichhornia crassipes* on Irrigation

Eichhornia crassipes was first reported in Ethiopia on the irrigation and drainage structures of WSSF in 1996 (Firehun *et al.*, 2007; Taye *et al.*, 2009). The high nutrient inputs from sewerage, factory waste, and flooding of additional inputs from the surrounding areas created ideal conditions for the spread of the weed mainly on reservoirs, irrigation supply, and drainage canals. *Eichhornia crassipes* restricted the proper flow of water in reservoirs, irrigation, and drainage canals. It reduced irrigation water and being with other waste materials from the nearby areas resulted in frequent flooding (Harley *et al.*, 1996; Firehun *et al.*, 2007).

2.4.3. Effects of *Eichhornia crassipes* on Water Transportation

Eichhornia crassipes have blocked waterways and hamper navigation, affecting boats by leading to the damage of hulls as they collide with objects under *Eichhornia crassipes* mats (Ndinwa *et al.*, 2012). *Eichhornia crassipes* mats prevent means of approaching harbors and jetties and clodding rivers and canals. *Eichhornia crassipes* is becoming a problem as it also prevents the

passage of marine vessels. According to Ndinwa *et al.* (2012), within the Delta region of Nigeria, operations of several boat harbors and maritime workers have been limited as the aquatic plant blocks facilities and damages boat ramps causing overheating in boat motors. *Eichhornia crassipes* decreases the use of facilities for boat rentals and other maritime businesses.

2.4.4. Effects of *Eichhornia crassipes* on Fish Catching

Eichhornia crassipes affect access to fishing grounds and fish catching ability (Kateregga & Sterner, 2009). Odidi (2014), stated that for the individual fisherman, *Eichhornia crassipes* causes difficulty in catching fish result in loss of fishing gear, time-wasting during fishing and difficulty in movement, and even sometimes preventing people from fishing. The hyacinth mats reduced their catch by covering fishing grounds, delaying access to markets due to loss of output, increasing fishing costs due to the time and effort spent clearing waterways, forcing translocation, and causing loss of nets (Mailu's, 2001)

Eichhornia crassipes cause several problems to fishermen in the riparian communities. When weed infestation is present, access to fishing sites becomes difficult for riparian communities which rely solely on fishing as their main economic activity (Munjigni, 2012). This leads to an increase in their expenditure on fuel for engine boats and an increase in the cost of the meager quantities of fish they catch, for society. There is often a loss of fishing gear when nets or lines become tangled in the root systems of the weed. All these lead to a reduction in fish catch and subsequent loss of livelihood.

2.5. Application of GIS and Remote Sensing on *Eichhornia crassipes* Detection

GIS and Remote sensing can provide a spatial snapshot on areas that experience aquatic weeds infestation and potentially vulnerable areas and/or monitor response to management interventions. Satellite remote sensing technologies can capture and instantaneously record earth surface information and provide a synoptic view of land surface characteristics and associated dynamics (Risser and Treworgy, 1985). Some of the remote sensing imagery devices have high spectral and spatial characteristics, which enable the enhanced monitoring of the spatial distribution and spread of invasive species. Advancements in remote sensing technology have enabled the mapping and monitoring of a range of invasive plant species at large scales (regional or global). Because of the limitations of each remote sensing technology, including temporal,

spectral, and spatial resolution, it is imperative to understand the appropriateness of each type of satellite data for mapping and monitoring *Eichhornia crassipes* infestation. Remotely sensed data of high spatial (0.5 m) and spectral (more than 100 bands) resolutions, such as hyperspectral, provide detailed information of an object with a high level of accuracy.

However, hyperspectral data are not free and expensive and often difficult to access for general use, which limits their access (Govender *et al.* 2007). Conversely, Landsat 8 with a swath width of 185 km per scene and high temporal resolution are available for use free and can provide good spatial distribution maps of certain vegetation (Dube *et al.*, 2015; Karlson *et al.* 2015). For instance, Matongera *et al.* (2017) used Landsat 8 to map the abundance and distribution of bracken fern (*Pteridium aquilinum*). Remotely sensed imageries of MODIS, MERIS, IKONOS and Landsat have been successfully used to identify and map *Eichhornia crassipes* in many regions of the world, and among these include those in the water systems of Southern Texas in North America (e.g., Lake Texana near Edna, the Frio River near Tilden and Rio Grande River in the Lower Rio Grande Valley (LRGV) (Everitt *et al.* 1999).

In recent years several scholars have been studied sensor comparisons of Landsat 8 and Sentinel-2 (Flood, 2017; Forkuor *et al.*, 2017; Korhonen *et al.*, 2017; Quintano *et al.*, 2018; Stumpf *et al.*, 2018; Wang *et al.*, 2018). Though, more information is needed regarding the differing capabilities of the two sensors for land cover mapping, monitoring, and change assessment. According to Thais *et al.* (2019), Sentinel-2 shows a better performance, the overall accuracy (96.7%) is just marginally higher than Landsat 8 (95.7%). Similar values were reported in other studies on land cover changes when comparing Landsat 8- and Sentinel-2-based results. Forkuor *et al.*, (2017), mapping land use and land cover in Burkina Faso, found that the usage of Sentinel-2 data can improve image classification accuracy by 4%. In another study, Sentinel-2 was also shown to better map burn scars and fire severity in Greece with a 2.7% higher overall accuracy compared to Landsat-based results (Mallinis *et al.*, 2017). A study in Finland (Korhonen *et al.*, 2017), compared the retrieval of biophysical variables for forests, concluded that Sentinel-2 performed better when the red-edge band was considered. However, the improvements in accuracy were marginal. Therefore, a better detectability of selective classification was expected due to the finer spatial resolution of Sentinel-2 than Landsat 8. Due to this, a Sentinel-2 satellite image was selected for the study.

2.6. Empirical Evidence

An exploration of the literature on *Eichhornia crassipes* indicates that various researches have been conducted on the expansion of *Eichhornia crassipes*, its impacts, and method of controlling and managing *Eichhornia crassipes*. Generally, studies that have been done on *Eichhornia crassipes* were summarized in Table 3.

Table 3: Empirical evidence

Study area	Title	Variables	References
Bora District	<i>Eichhornia crassipes</i> in a Different Realm	<i>Eichhornia crassipes</i> and land	Gobena & Berhanu (2019)
East Shoa	<i>Eichhornia crassipes</i> : Land use/land cover changes and community-based management	<i>Eichhornia crassipes</i> and LULC change	Ebro <i>et al.</i> (2017)
Ethiopian Rift Valley	Management of <i>Eichhornia crassipes</i> using bioagents	<i>Eichhornia crassipes</i> and Bioagents	Firehun (2017)
Wonji-Shewa	Distribution, Impact and Management of <i>Eichhornia crassipes</i>	<i>Eichhornia crassipes</i> and impacts	Firehun <i>et al.</i> (2007)
Lake Tana	<i>Eichhornia crassipes</i> Impacts on Hydrology and Ecosystem Services	<i>Eichhornia crassipes</i> and impacts	Gitaw <i>et al.</i> (2019)
Lake Tana	Detecting Spatiotemporal Expansion of <i>Eichhornia crassipes</i>	<i>Eichhornia crassipes</i>	Damissie (2020)
Lake Tana	<i>Eichhornia crassipes</i> Biology and its Impacts on Ecosystem, Biodiversity, Economy and Human Well-being	<i>Eichhornia crassipes</i> & Impacts	Degaga (2018)
Lake Tana, Ethiopia	Challenges of managing the impact of invasive plants on the environment	Challenge and impacts	Hiruy (2019)
Rwanda	Mapping distribution of <i>Eichhornia crassipes</i> using multispectral remote sensing imagery	<i>Eichhornia crassipes</i>	Mukarugwiro <i>et al.</i> (2019)
Tzaneen, South Africa	Remote sensing of invasive <i>Eichhornia crassipes</i>	Remote Sensing & <i>Eichhornia crassipes</i>	Humphrey and Dube (2018)
Masvingo, Zimbabwe	Socio-ecological Impacts of <i>Eichhornia crassipes</i> Under Dry Climatic Conditions	<i>Eichhornia crassipes</i> and effects	Chapungu (2018)
Njoro, Kenya	The effect of <i>Eichhornia crassipes</i> infestation on phytoplankton productivity and the status of control	<i>Eichhornia crassipes</i> & effects	Momanyi (2004)
Kisumu County, Kenya	Influence of <i>Eichhornia crassipes</i> on livelihoods	<i>Eichhornia crassipes</i> and influence	Odidi (2014)
Nigeria	Impact of <i>Eichhornia crassipes</i> infestation in waters: utilization and management	<i>Eichhornia crassipes</i> , impacts and management strategies	Ovarr (2019)
Madin dam, Mexico	Monitoring the expansion of <i>Eichhornia crassipes</i>	<i>Eichhornia crassipes</i>	Daniel (2020)

2.7. Conceptual Framework

The study was focused on the expansion of *Eichhornia crassipes* and its impacts on the major livelihoods of the community. So as *Eichhornia crassipes* expansion increase to other land uses, its impact on the livelihoods such as irrigation, fish catching, water transportation, and *Typha latifolia* harvesting activities become high.

Hence, the one to other arrow describes there is a relationship between *Eichhornia crassipes* expansion and the livelihoods of the society. However, their relationship is the inverse relationship. The up and down arrows describe when the expansion of *Eichhornia crassipes* increased into other land uses, it negatively affecting the livelihoods of the society. The conceptual framework of the study is summarized and described in Figure 3.

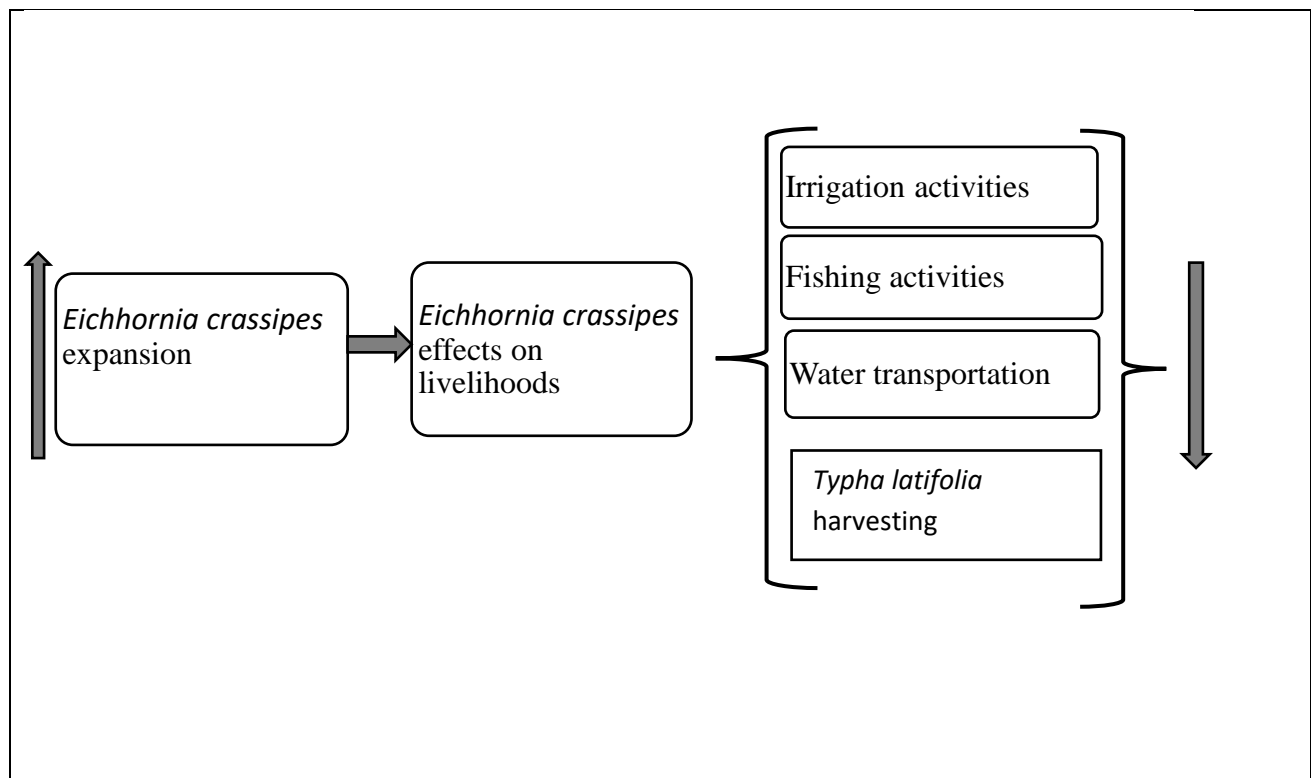


Figure 3: Conceptual framework of the study

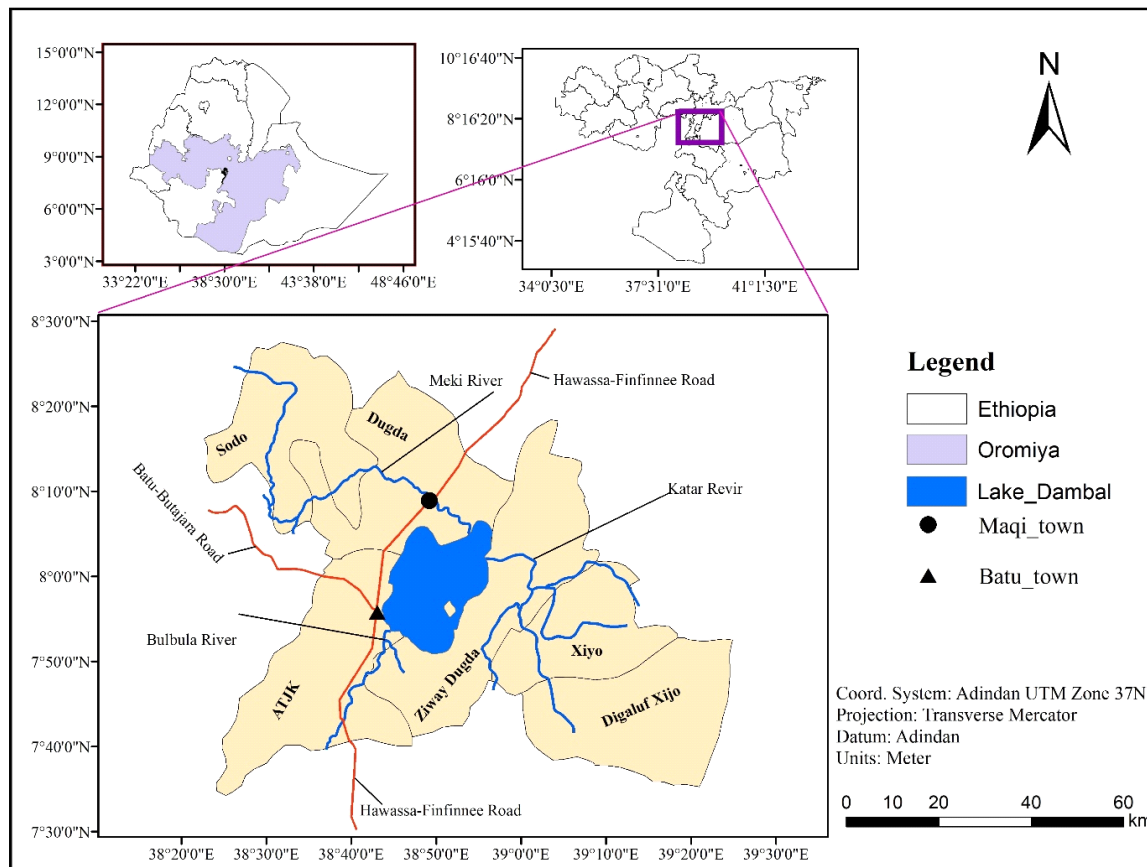
CHAPTER THREE

MATERIALS AND METHODS

3.1. The Study Area

3.1.1. Location

Lake Dambal is located about 160 km to the south of the capital city Finfinnee, Ethiopia. The Lake is between 7° 51' N to 8° 07' N Latitude and 38° 43' E to 38° 56' E Longitude (Lemma and Desta, 2016; Abrahama *et al.*, 2018). The location map of the study area is presented in Figure 4.



3.1.2. Lake Dambal Geometry

The surface area and the shoreline length of the Lake are 442 km² and 137 km, respectively (Author, 2021). The mean minimum and maximum depths of Lake Dambal are 2.5 m and 9 m, respectively (Desta *et al.*, 2015; Erko *et al.*, 2016; Teklu *et al.*, 2018). The difference in the reported depth of the Lake by several authors seems partly explained by the remarkable seasonal rainfall variation (Tamire, 2012). The districts bordering the Lake are ATJK, Dugda, and Ziway

Dugda (Desta *et al.*, 2017). The town Batu lies on the western shore of the lake, and Maqi town is also located on the northern shore of Lake Dambal.

Lake Dambal watershed falls between 7°30'N to 8°30'N Latitude and 38°20'E to 39°30'E Longitude covering a total area of about 6991 km² (Author, 2021). It contains three river systems, namely Katar and Maqi Rivers which are flowing toward Lake Dambal and Bulbula River discharging toward Lake Abiyata. The watershed lies in two Ethiopian administrative regions; 73.6% in Oromia National Regional State (ONRS) and the remaining part in Southern Nation Nationalities and People Regional State (SNNPR). Katar sub watershed is located within ONRS while Maqi sub-watershed is scattered over ONRS and SNNPR.

3.1.3. Climate

The Mean Monthly Annual Temperature and Rainfall of the study area were obtained from Ethiopian Metrology and described in Figure 5 and 6, respectively.

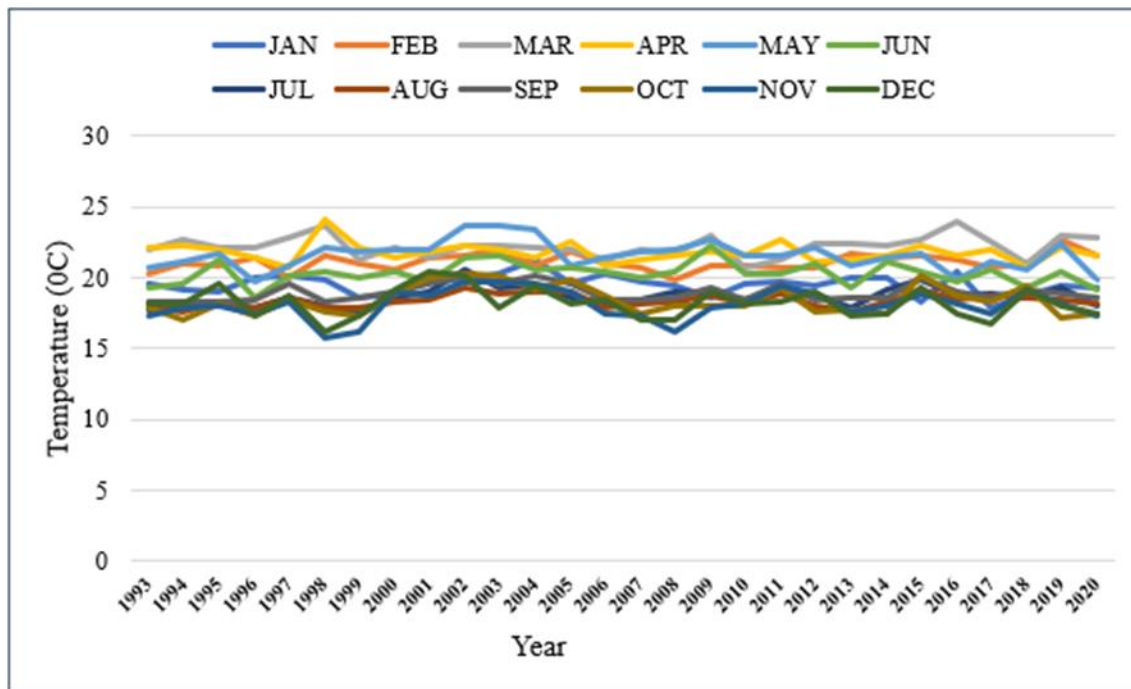


Figure 5: The mean monthly annual temperature (Ethiopian Metrology, 2021)

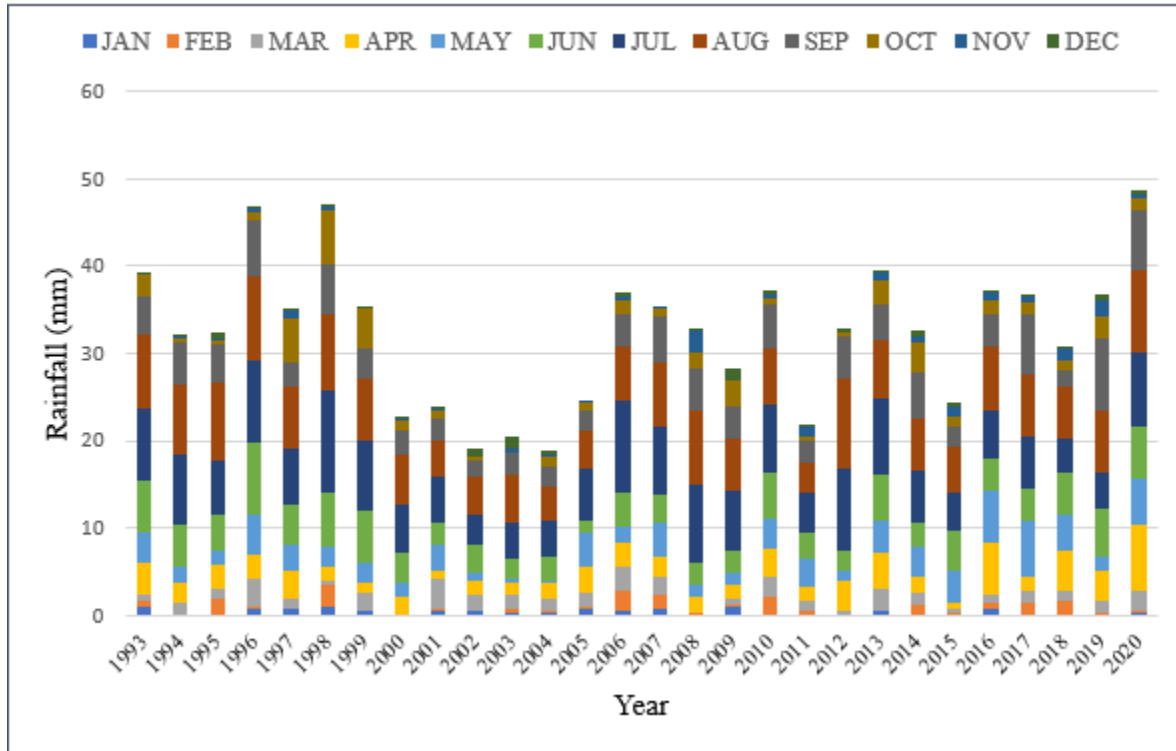


Figure 6: The mean monthly annual rainfall (Ethiopian Metrology, 2021)

3.1.4. Population

About two million human populations (CSA, 2013) and about 1.9 million livestock (Tsegaye *et al.*, 2012) inhabit the Lake Dambal watershed. It is the most upstream of the Central Rift Valley (CRV) Lakes of Ethiopia. The settlement pattern is typical of rural communities (Stellmacher, 2015). Livelihoods largely depend on smallholder agriculture.

3.1.5. Land Use Land Cover

The dominant land covers around the Lake are agricultural cultivation, wetland, grazing land and water (Wondimagegnehu *et al.*, 2019). Irrigated agriculture is common especially along with the courses of the Meki River, Katar River, Bulbula River and around Lake Dambal. Onion, tomato, cabbage, pepper, beans, maize, fruits and vegetables are widely cultivated in many private and state farms in the area (Abrahama *et al.*, 2018). Land cover change is massively and rapidly taking place, as elsewhere in the Ethiopian CRV (Dadi *et al.*, 2016).

3.1.6. Topography

The altitude of the Lake Dambal catchment ranges from 1570 to 3992 m asl. with a mean elevation of 2226.27 m asl. The major part of the watershed has an elevation of more than 1745 m asl. This shows that during the rainy season much amount of surface water is drained to the Lake due to its elevation. The topographic map of the Lake Dambal catchment is described in Figure 7.

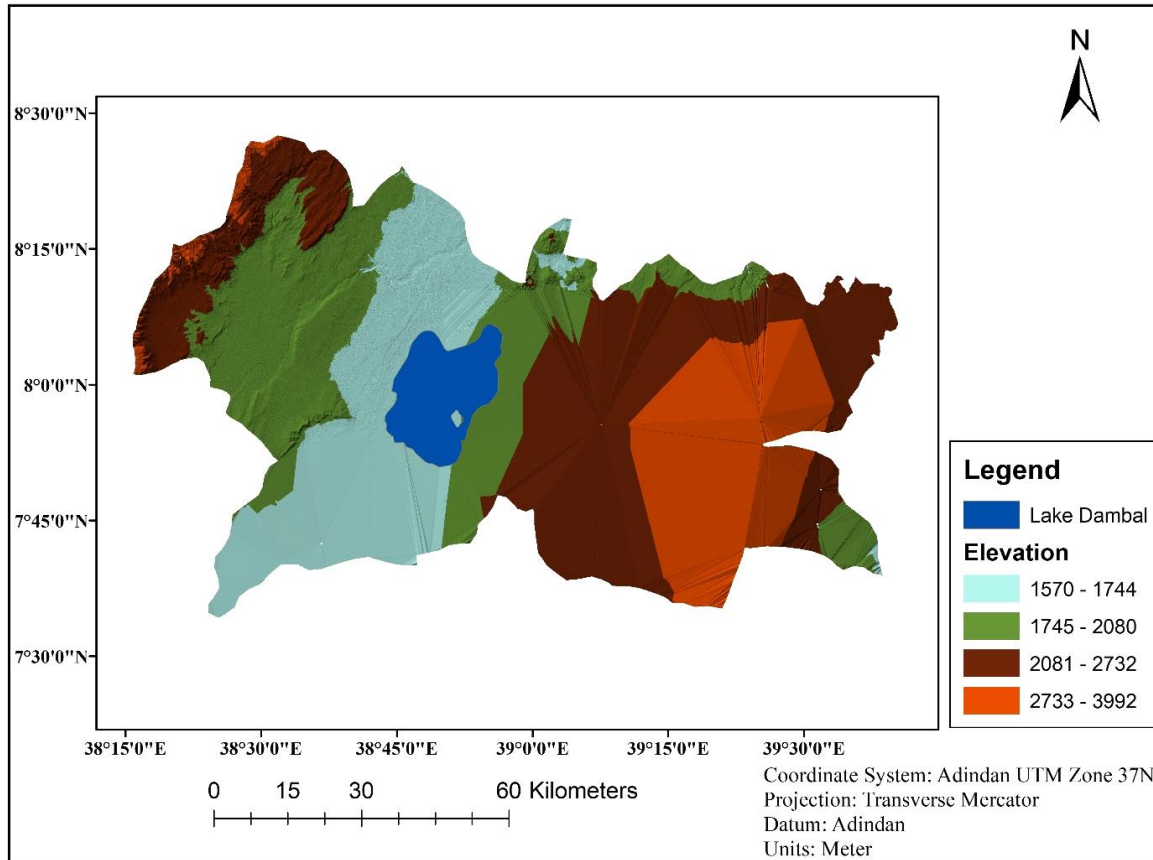


Figure 7: Topography of Lake Dambal catchment (Ethio-DEM, 2021)

3.2. Research Design

Research design is the framework of research, which comprises the most vital features and guidelines for planning data collection and data analysis (Inaam, 2016). The study was adopted the mixed-method approach of both quantitative and qualitative data. The concurrent mixed method approach composed of quantitative and qualitative data was employed for the study. This means that both quantitative and qualitative data were collected simultaneously and the results were embedded during the analysis.

To analyze the *Eichhornia crassipes* expansion, to answer basic research questions and to attain the intended objectives of the study; the researcher was preferred and adopted mixed-method (qualitative and quantitative data) that were collected from primary and secondary sources.

3.3. Software

Various software has been used for this study for different purposes. ArcGIS software was used for mapping the study area, streams flow to Lake Dambal, the topography of Lake Dambal watershed and change detection of *Eichhornia crassipes* expansion and other land uses from 2017 to 2021. QGIS software has been used for pre-processing like layer stacking and calibration before image classification was done. The eCognition software was used to classify the image of each year and their accuracy assessment. Finally, SPSS software has been used to analyze data regarding the impacts of *Eichhornia crassipes* on the livelihoods of society. Generally, a summary of software and its purposes are listed in Table 4.

Table 4: The software used

Software	Product	Released	Purposes
ArcGIS 10.5	ESRI	2016	Locate the study area; map streams flow into the lake; topographic mapping; area calculation & change detection
QGIS 3.6.3	GeoApt	2019	Image pre-processing
eCognition Develop 9	Trimble German	2000	Image classification and accuracy assessment
SPSS 20	IBM	2012	Quantitative and qualitative data processing and analyzing.

3.4. Sampling Techniques and Sample Size

3.4.2. Sampling Techniques

There are 31 number of Peasant Associations (PAs) that are found along the lake's shoreline. To assess the effects of *Eichhornia crassipes* on the livelihoods of the societies, the sample respondents were taken from all PAs found along the lake's shoreline. The proportional allocation of a sample size to each peasant association was determined (Table 5). A simple random sampling technique was used to select the respondents in each peasant association for questionnaires. This technique ensures that each population has an equal and independent chance

of being selected. Random lists of numbers that correspond to the number of households represented in the PAs were generated and then the households included in the sample were picked at random from each list.

3.4.1. Sample Size

The sample size used in the study was generated from the target population who live in the peasant associations found along the Lake's shoreline. Therefore, the sample size was determined by using Yemane (1967:886) formula at 95% confidence interval.

$$n = \frac{N}{1+(N*e^2)} \dots\dots\dots(1).$$

Where n is the sample size; N is the population size, and e is the level of precision (acceptable margin of error) at 95% confidence interval ($5\%=0.05$). Therefore, the calculated sample size was 395 respondents (Appendix V).

According to FAO (1990), during sample size determination; there should be a contingency of sample because there might be non-response or recording error. Therefore, 5% of the calculated sample size was taken as a contingency. Contingency (5%) = $395*(5/100) = 19$. The total sample size used for the study was 414.

Table 5: The proportionate allocation of households sampled from each peasant association

Name of Peasant Association	Number of households	Number of households sampled
Tuchi Dambal	727	9
Wayyo Gabriel	553	7
Abono Gabriel	329	4
Dodota Dambal	479	6
Tepo Corroqe	642	8
Giraba Qorke adi	870	11
Baqale Girrisa	820	10
Walda Maqdala	821	10
Walda Qalina	944	12
Darara Dalacha	704	9
Burqa Dambal	689	9
Walın Bula	1001	13
Nagalinye	440	6
Elka Chalamo	1076	13
Edo Gojola	632	8
Abune Garmama	1086	14
Malka Shallo	6530	82
Malka Wafiqo	8050	101
Boccesa	676	8
Dodicha	654	8
Abay Danaba	762	10
Aluto	608	8
Bishara Chafa	365	5
Herera	230	3
Chafa Burqitu	419	5
Maja Shanan	406	5
Burqa Lamaffo	448	6
Sango	282	3
Golbe	409	5
Sanbaro	475	6
Ganale	431	5
Chafa Jila	418	5
Total	32976	414

Source: Plan & Safety Net Program (2021)

3.5. Data Types and Sources

The study included both spatial and non-spatial (socio-economic) data types. Spatial data was Sentinel_2 remote sensing satellite image and non-spatial data were data about impacts of *Eichhornia crassipes*. Therefore, both primary and secondary data sources were used for the study.

3.5.1. Primary Data

Sentinel_2 satellite image, ground control point and data from households about the effects of *Eichhornia crassipes* on livelihoods were primary data. Studies have been reported that Sentinel_2 satellite images better-classified land cover types when compared to Landsat 8 (Labib and Harris, 2018). So, Sentinel_2 image was used to detect *Eichhornia crassipes* from other land covers. The Sentinel_2 satellite images used for the study were two-years consecutive differences (2017 -2019 and 2019 - 2021) to map the expansion of *Eichhornia crassipes*. The images (2017 & 2019) were downloaded from the United States Geological Survey (USGS) Global Visualization Viewer (GloVis) (<https://earthexplorer.usgs.gov/web-link>) and image of 2021 was obtained from Copernicus Hub Open Access to provide a synoptic view of the study area. The image captured during the dry season were selected to reduce confusion with the growth of green plants like grass from *Eichhornia crassipes* (Ruelland *et al.*, 2011). So that, the image captured during the dry season (January or February depending on their cloud cover) of 2017, 2019 & 2021 were selected.

Ground truth data were used for image classification and validation. To accomplish this task, enough training samples were collected. So that, the training samples were collected in April 2021 by GPS Garmin 72H. According to Mather and Koch (2011), at least 30 points per class are needed for image classification. Besides, the accuracy of land cover classification depends on the amount of sample and the accuracy of training data used (Hsiao and Cheng, 2016). As the number of ground truth increases the classification accuracy also increased. For the study, 190 total ground truth points were collected for both image classification and validation.

The questionnaire is one of the data collection instruments from sample respondents identified for the study. The semi-structured questionnaires were distributed to the selected respondents living around Lake Dambal. The data of the impact of *Eichhornia crassipes* on the livelihoods of

the local communities were collected through the distributed semi-structured questionnaires (Appendix I).

Feld observation was another tool for data collection. The observation was used to guide the researcher during data collection. This tool was used to observe the status and distribution of *Eichhornia crassipes* around the shoreline of the Lake (Appendix III).

3.5.2. Secondary Data

Secondary data are data published or documented by someone else. The secondary data sources are relevant published and unpublished materials including books, scientific reports and other official publications related to the area of the study were collected.

3.6. Satellite Data Processing

Satellite images were processed for further analysis. Therefore; pre-processing, image classification and post-processing were done for the Sentinel_2 satellite image.

3.6.1. Pre-processing

Illumination, weather condition and sensor noise variation are the main causes of distortion on the remotely sensed image (Hadjimitsis and Themistocloud, 2008). The aim of pre-processing is to improve unwanted distortion and make the image for further analysis. QGIS software was used to correct the Sentinel_2 image obtained from USGS. For clear classification of land cover types of the area near the Lake, the image captured at the band (2, 3, 4, and 8) were selected, because at these bands the image has a high spatial resolution (10m) and spectral reflectance. So that, layer stacking (merge) of Band_2, Band_3, Band_4 and Band_8 of Sentinel_2 satellite image was done. Calibration was done to convert the image from digital number (DN) to top of atmosphere (ToA) or reflectance.

3.6.2. Image Classification

Studies have verified that Object-Based Image Classification has greater potential for classification than pixel-based image analysis (Dronova, 2015). So, for this study Object-Based Image Analysis was used to classify the image. The pre-processed sentinel-2 images were segmented into individual image objects in an object-based approach by eCognition. A multiresolution segmentation algorithm was used to create image objects. Multi-resolution segmentation is a bottom-up region-merging technique starting with one-pixel objects

(Nussbaum *et al.*, 2008). The segmentation was performed to group contiguous pixels into areas or segments that are homogenous based on criteria: scale, color and shape. The images were segmented by defined parameters at scale (200), shape (0.2) and compactness (0.8). After parameters were defined, eCognition produced a new image with a new group of pixels.

The created image objects should present the objects in reality. Then class hierarchy was generated. After generating a class hierarchy, the segmented image was classified based on ground truth and spectral signature value. The images were segmented through steps described in Figure 8.

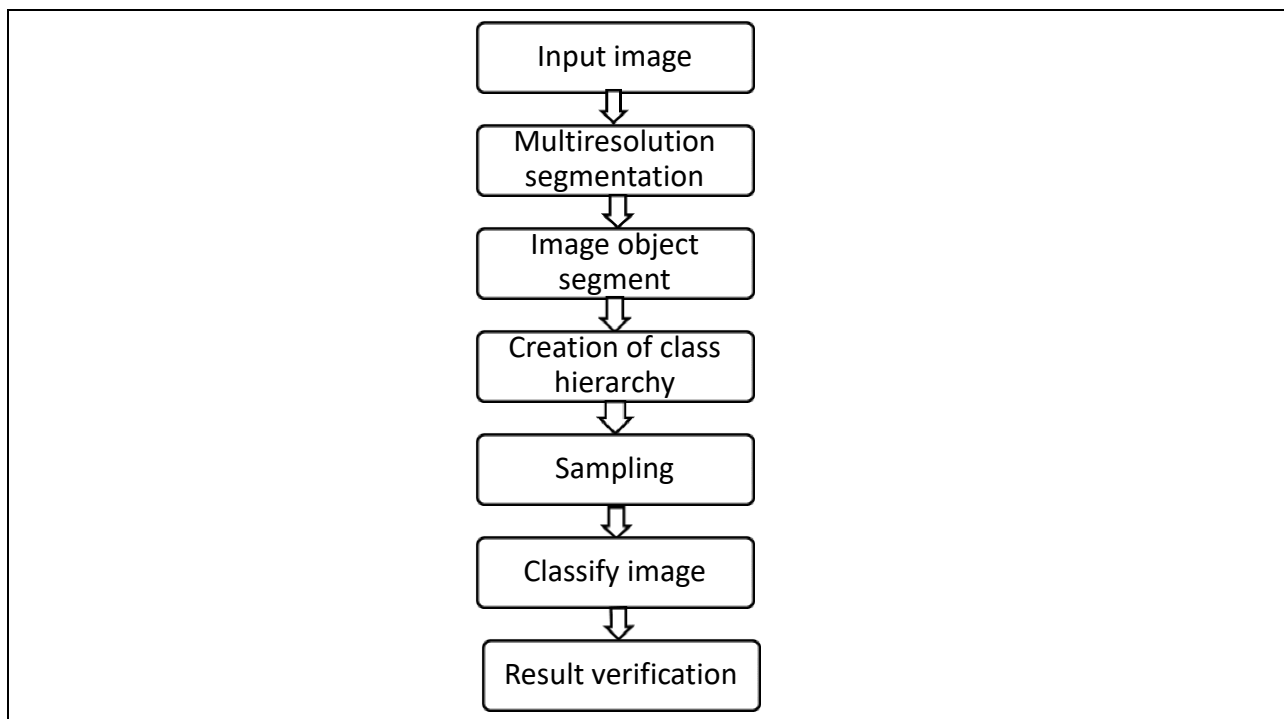


Figure 8: Chart of image classification.

3.6.3. Post-Processing

Post-classification was used in classification procedures to calculate the accuracy of the classified images. It is the final step in the analysis of remote sensing satellite images which helps to verify the result.

i. Accuracy Assessment

To evaluate the predictive map of *Eichhornia crassipes* distribution and land cover types developed by the multiresolution segmentation algorithm, an independent test dataset in

confusion matrices was used to compare the true class with the classes assigned by the classifiers. The overall accuracy, producer accuracy, user accuracy and the Kappa coefficient were obtained as described by Congalton and Green (2008). Accuracy assessment was calculated for the image of 2021 on eCognition software by error confusion matrix based on ground truth. eCognition software has the advantage to determine the accuracy of the previous image without a ground control point.

Therefore, the accuracy of 2017, 2019 and 2021 images were assessed on eCognition software. But the overall accuracy, Producer accuracy and user accuracy can be described by equations 2, 3 and 4 respectively.

$$\text{Over All Accuracy} = \frac{\text{Total number of correctly classified pixels}}{\text{Total numbers of pixels}} * 100 \dots\dots\dots (2).$$

$$\text{User Acc.} = \frac{\text{Total number of correct pixels in a category}}{\text{Total numb.of pixels of that category derived from the reference data(col tot.)}} \dots\dots\dots (3).$$

$$\text{Prod. Accu.} = \frac{\text{Total number of correct pixels in a category}}{\text{Tot.numb.of pixels of that category derived from the reference data(row tot.)}} \dots\dots\dots (4).$$

Another measure of classification accuracy is the Kappa coefficient, which is also calculated to provide a measure of the difference between the actual agreement, and reference data used to perform the classification (Congalton and Green, 2008). Using this technique, it is possible to test if an individual land cover generated from the remotely sensed image is better than the map generated by randomly assigning labels to areas. Kappa of 2017, 2019, & 2021 images was automatically calculated by eCognition software. It also possible to calculate by using equation (5).

$$\text{Kappa} = \frac{\text{Probability of commission} - \text{probability of omission}}{1 - \text{probability of comission}} \dots\dots\dots (5).$$

ii. Feature Space Plots

Defining class separability is analyzed through the spectral value of each class and feature space plots (Gong and Howarth, 1989; Chen and Stow, 2002). So, after the image was classified into different classes, the feature space plot of each class was derived on eCognition. This is important to check the classes in classified images.

Bands with high separable class values were selected to analyze the classification. Therefore, layer 3 (band 4) and layer 4 (band 8) of 2021 were used for the feature space plot to differentiate *Eichhornia crassipes* from other classes (Figure 13).

iii. Change Detection

Change detection uses multi-temporal datasets to identify the state of an object or any occurrence by detecting it over time (Chen *et al.* 2012). The changes in land cover types are characterized by spatial and temporal dimensions. In this study, three land use maps (2017, 2019, and 2021) were created. The map from 2017 was compared with the maps of 2019 and that of 2021 for each category of land uses. Finally, the extent change for each land use type of different year was obtained (Table 10).

3.7. Socio-economic Data Analysis

Both quantitative and qualitative data collected from respondents through questionnaires were analyzed. The data collected were coded and transferred into the SPSS software (Version 20). Descriptive statistics such as frequency counts, percentages and cross-tabulation were used for data analysis and the outputs were presented in Table. Finally, a one-way analysis of variance (ANOVA) was employed to analyze the effects of *Eichhornia crassipes* on each livelihood activity.

3.8. Data Reliability and Validity

3.8.1. Data Validity

Validity is how much data collection method accurately measures what researchers are planning to measure (Saunders *et al.*, 2007). When applying this to data collected through a questionnaire it means that the data collected is the data that actually should be collected. Therefore, in time of preparing the items of the questionnaire, simple words that the respondents can easily understand were used. The effort was made to check that the items of questionnaires are clear and precise with no uncertainty to properly address the objective of the study.

The instrument was given to advisors for judgment and to review its' contents and soundness. Finally, the questionnaire was translated to Afan Oromo, which is the language that the households can easily understand to give responses (Appendix II).

3.8.2. Data Reliability

Mugenda and Mugenda (2003), states that reliability measures the consistency of results. A reliable instrument is one that consistently produces the result when used more than one to collect data from households. The test-retest reliability approach was used to check the consistency of the result. According to Mugenda and Mugenda (2003), this approach involves administering the same instrument (questionnaires) twice on the same sample households at different times. Machmaids and Nachmias (1996), in addition states that the instrument is administered at two different times and then computes the correlation between the sets of scores. Therefore, questionnaires were pilot-tested on a sample of 10 households (respondents) from one peasant association. After a week the same questionnaires were administered to the same households and then a Pearson correlation coefficient was calculated.

The mean Pearson correlation coefficient achieved was 0.93 (93%), it shows that there is strong consistency of results (answers) obtained from households.

3.9. Ethical Consideration

Ethical measures are principles that the researcher should fix himself with in conducting his/her research. For the study, the researcher is requiring approvals for researching data collection (McMillan & Schumacher, 1993). Authority to conduct the study was granted from Jimma University (Appendix IV). The agreement with the university was informed to the district's administration office. This agreement was then informed to respondents before explaining the purpose and importance of the study. The participant's norms, values, and rights should be respected and protected during data collection. In this study, participants' confidentiality was respected, as they were not asked to provide their names on the questionnaire during data collection.

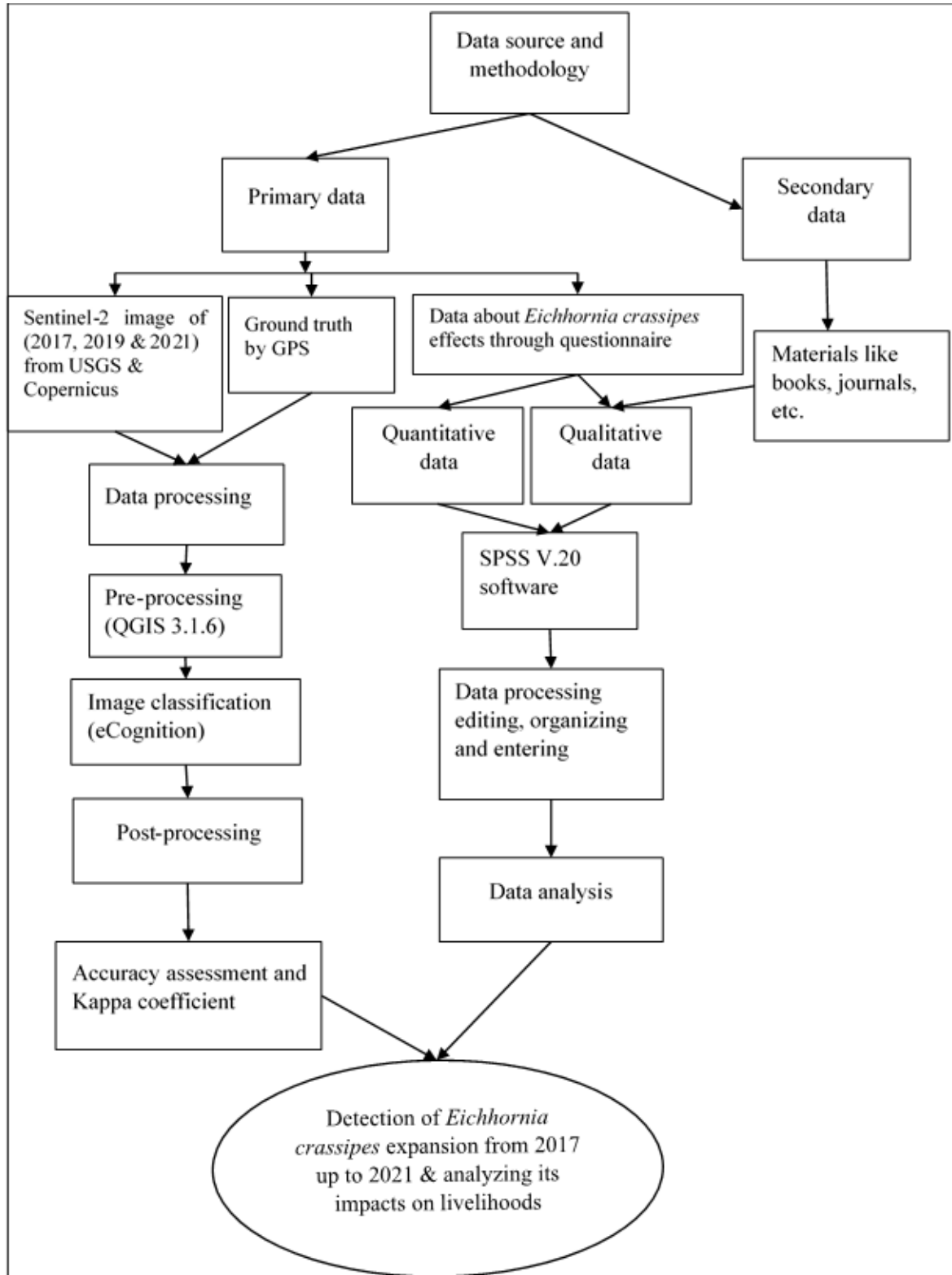


Figure 9: Flow chart of methods

CHAPTER FOUR

RESULTS AND DISCUSSIONS

This chapter presents the results and discussions of the findings in major seven sections. The first section deals with the results on land use classification and the extent of *Eichhornia crassipes* expansion from 2017 – 2021. The second section was about the change of *Eichhornia crassipes* in two years intervals. The third section described the response return rate. The fourth section is about demographic characteristics of the respondents including gender, age, educational status, marital status, family size and respondents' livelihood type. The fifth section shows the general information regarding *Eichhornia crassipes*, the sixth section analyzed the impact of *Eichhornia crassipes* on the major livelihood activities of the community and finally, the last section described the benefits of *Eichhornia crassipes*.

4.1. Land Use Classification

4.1.1. Land Use Coverage in 2017

The classification results show that the proposed method classifies the image into different major five classes (Figure 10). In the year 2017, *Eichhornia crassipes* was having small coverage, consisting of 32.51 ha (0.06%) of the total study area, which was 52,285.4 ha (Table 6). Whereas, 40,938.35 ha (78.29%) of the study area was covered with a water body and 11,314.54 ha (21.65%) of the area was occupied by wetland, grazing land (including Settlement & Iceland) and irrigated land. Some peripheries of the lake particularly on the western and northern sides were covered in a small amount with *Eichhornia crassipes*. But *Eichhornia crassipes* coverage in the year 2017 was concentrated only in the southwestern around Batu town, peripheral part of the study site. Generally, the expansion of *Eichhornia crassipes* in the 2017 year is presented in Figure 10 and its extent in hectare & percent is described in Table 6.

Table 6: Area of land use coverage in 2017

Class name	Area	
	Ha	%
Grazing land	3352.73	6.40
Irrigated land	2233.74	4.30
Wetland	5728.07	10.95
Water	40938.35	78.29
<i>Eichhornia crassipes</i>	32.51	0.06
Total	52,285.4	100

Source: Own survey (2021)

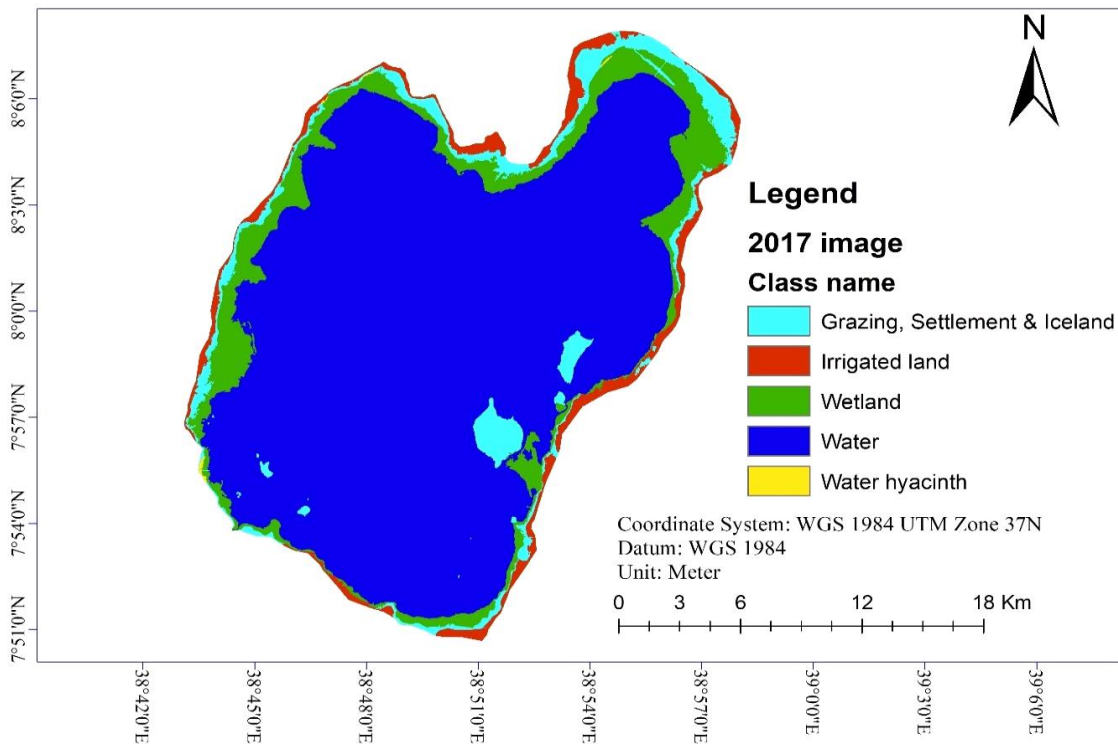


Figure 10: The classified image of 2017

4.1.2. Land Use Coverage in 2019

In the year 2019, the estimated *Eichhornia crassipes* coverage was 64.92 ha (0.12%) of the study area (Table 7). As compared for *Eichhornia crassipes* in the 2017 year, its coverage was increased by 32.41 ha which is 0.06% increment in the 2019 year. According to this result, a

double increment of *Eichhornia crassipes* was recorded in 2 years interval means between 2017 and 2019. This implies there was a fast expansion of *Eichhornia crassipes* in specified period of time. This indicated that such an increase in *Eichhornia crassipes* coverage takes the adjacent area under its control in a short period. Whereas water bodies covered 79.32% of the area of the study site in 2019, 1.03% increase in water coverage. But wetland, grazing land and irrigated land were decreased by 0.23% (123.61 ha), 0.42% (228.27 ha) and 0.44% (213.34 ha), respectively. The total reduction of these land use were 565.22 ha; 532.81 ha was taken over by the water and 32.41 ha was taken over by *Eichhornia crassipes*. In 2019, fast expansion of the water body and *Eichhornia crassipes* coverage were observed specifically in the northern and southern part of the lake respectively as recognized from Figure 11.

The increment of water bodies in the 2019 year was due to the occurrence of the high amount of rainfall. There was much amount of water recharged to the lake as compared to water discharged from Lake Dambal; this causes flooding in the area and increased the extent of the lake into other land uses. Studies showed that Lake water levels can be fluctuated due to overexploitation of water bodies by humans, climatic and hydrological conditions of lake water bodies (Zohary *et al.*, 2011). The lake level increases at the end of the rainy season and decline at the end of the dry season. So as the extent of the water body increases the *Eichhornia crassipes* coverage also increased. A study by Dersseh *et al.* (2020) reported that the area covered by *Eichhornia crassipes* and the lake surface area was positively correlated with Pearson’s correlation coefficient of 0.41, which indicates a positive correlation between the *Eichhornia crassipes* covered area and lake surface area.

Table 7: Area of land use coverage in 2019

Class Name	Area	
	Ha	%
Grazing land, Settlement & Iceland	3124.46	5.98
Irrigated land	2020.4	3.86
Wetland	5604.46	10.72
Water	41471.16	79.32
<i>Eichhornia crassipes</i>	64.92	0.12
Total	52,285.4	100

Source: Own survey (2021)

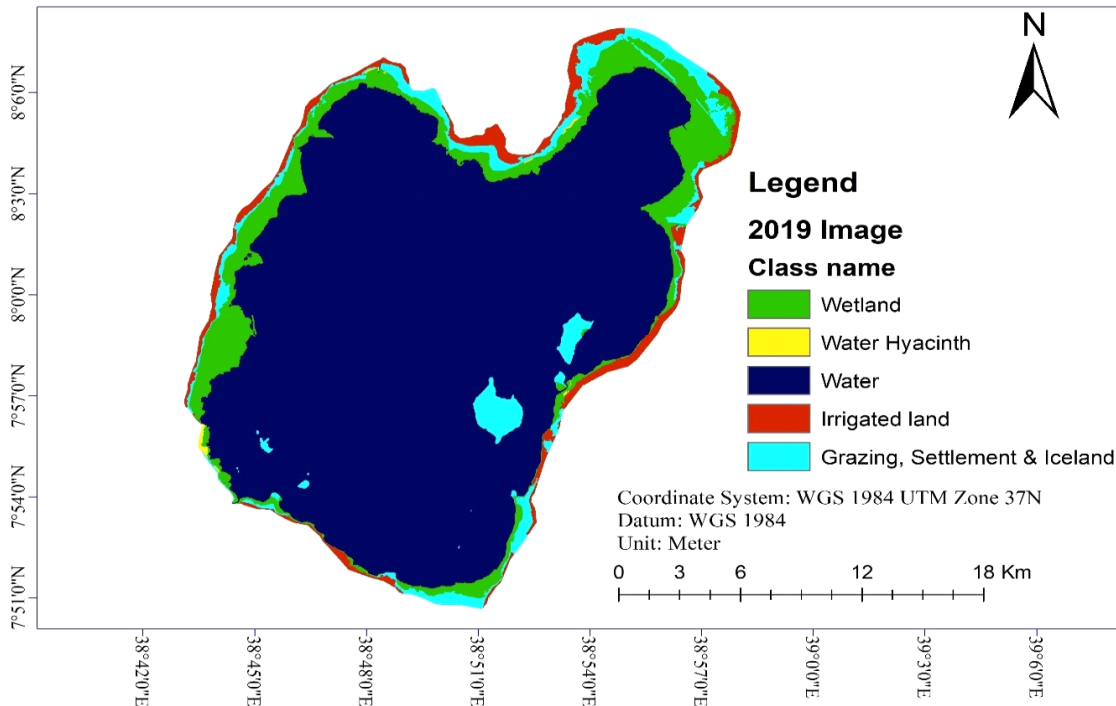


Figure 11: The classified image of 2019

4.1.3. Land Use Coverage in 2021

In the 2021-year *Eichhornia crassipes* was covering an area of 317.69 ha (0.61%) of the entire study site (Table 8). As compared to the *Eichhornia crassipes* coverage in the 2019 year, in 2021-year *Eichhornia crassipes* coverage was increased by 252.77 ha, which is 0.49% increment in 2 years of a time interval. This expansion of the *Eichhornia crassipes* was observed over grazing land and irrigated land. The increase in the invasion of the weeds could be because the *Eichhornia crassipes* could use nitrate and phosphate that come to the water body through runoff from the intensive agricultural lands surrounding the lake. The process could be like eutrophication. Flooding has occurred and the lake extent was increased into grazing and irrigated land particularly in the northern part of the lake.

A similar study conducted at Madin dam (Mexico) reported that the continuous growth of *Eichhornia crassipes* is determined by the availability of nutrients like nitrates and phosphates (Daniel, 2020). The *Eichhornia crassipes* grow effectively and rapidly in water with high nutrient concentrations and doubles on the surface of freshwater every 4-7 days (Luis & George, 2000).

In 2021, a high expansion of *Eichhornia crassipes* was detected in the study site and more marked in the south western and northern part of the study area (Figure 12).

Other similar studies conducted by Verma *et al.* (2003) on six lakes of India observe phenomena. The expansion of the *Eichhornia crassipes* is largely toward water bodies, wetlands and cropland. But in the study area, the expansion of *Eichhornia crassipes* is toward the grazing land and irrigated land rather than towards the water body. This occurrence has happened because of much amount of rainfall that occurred during the Ethiopian summer season (June, July & August) in 2020. Due to that *Eichhornia crassipes* was expanded to other land uses with water.

Table 8: Area of land use coverage in 2021

Class name	Area	
	Ha	%
Grazing land	2327.52	4.45
Irrigated land	1278.96	2.45
Wetland	5893.47	11.27
Water	42467.76	81.22
<i>Eichhornia crassipes</i>	317.69	0.61
Total	52,285.4	100

Source: Own survey (2021)

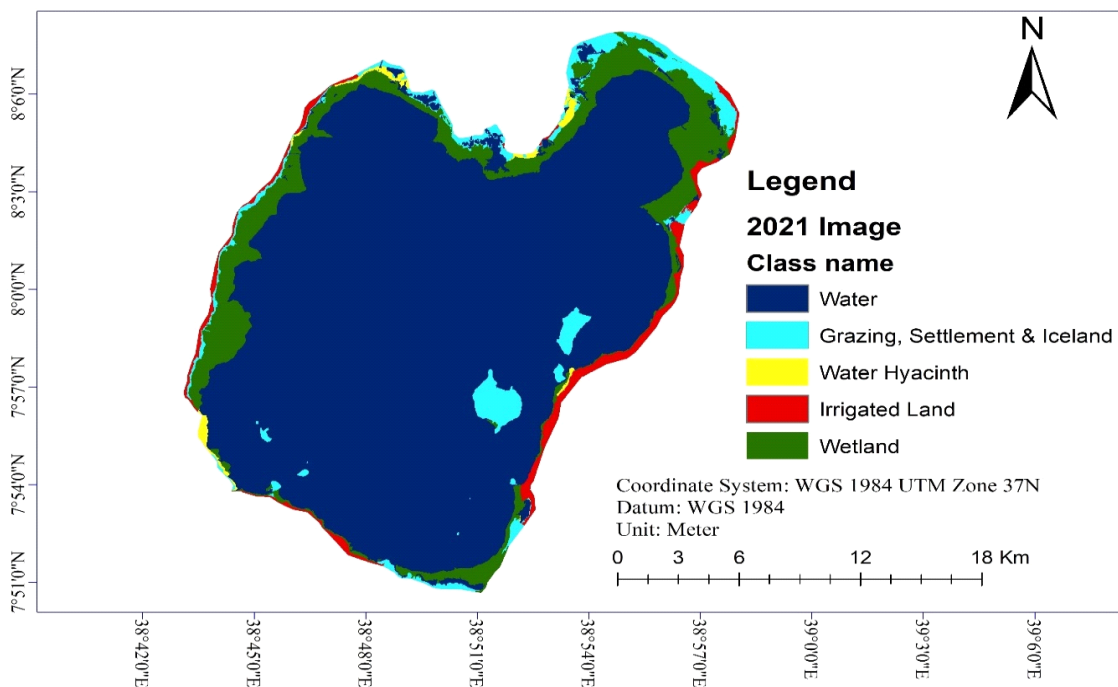


Figure 12: Classified image of 2021

The feature space plot is verification for image classified in the 2021 year. It plotted based on layer 3 (band 4) and layer 4 (band 8) of the 2021 image. The feature space plot is described in Figure 13.

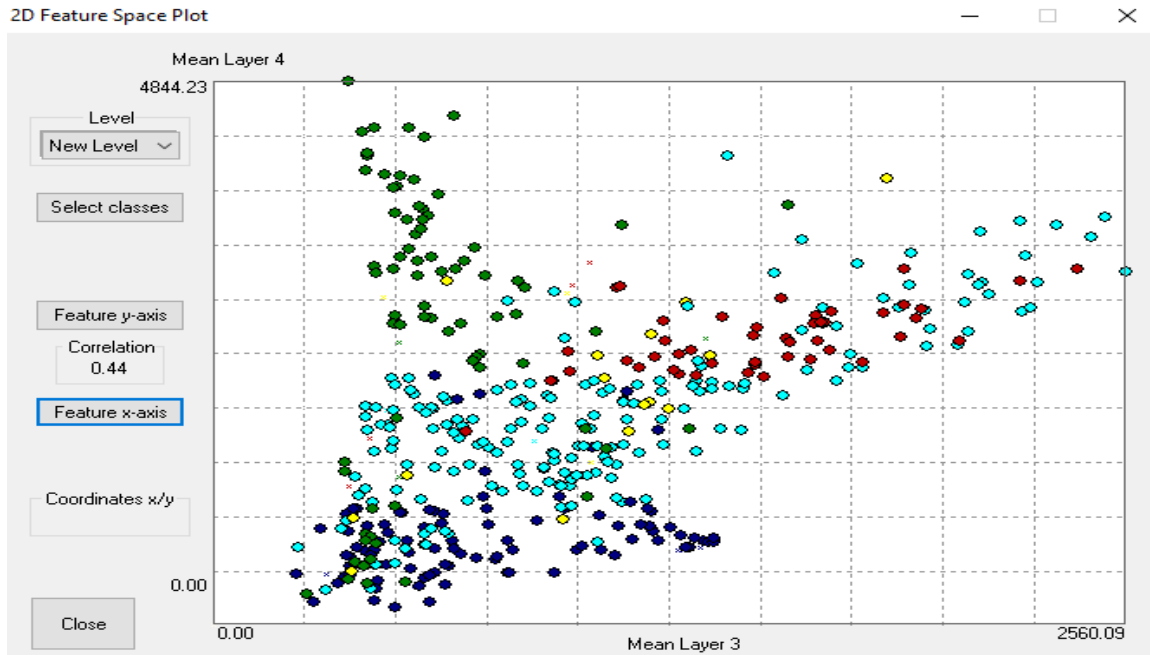


Figure 13: Feature space plot of 2021 image; blue: water; red: irrigated land; yellow: *Eichhornia crassipes*; cyan: grazing, settlement & Iceland; and green: wetland

4.1.4. Classification Accuracy of 2017 to 2021 Image

Accuracy assessment helps to know the accuracy or goodness of the classified images to the purpose required (Congalton and Mead, 1983; Story and Congalton, 1986). Accuracy assessment of the classified maps was done for the classified image of 2021 which has ground truth data. *eCognition* software can also determine the accuracy of the classified image that hadn't ground control point. So, the accuracy of 2017 and 2019 images were assessed. The overall accuracy of 2017-, 2019-, and 2021-year images were 0.9434, 0.9933 and 0.9172 respectively. And the Kappa Index of Agreement (KIA) of 2017-, 2019- and 2021-year images were 0.9168%, 0.99% and 0.8873%, respectively. Based on the information described in Table 9, the KIA value of each image was above 0.81. This shows that the images were classified in good and almost perfect agreement. The accuracy of the classified image of each year was described in Appendix VI. Besides, the producer accuracy, user accuracy, overall accuracy and KIA of the year 2017, 2019 and 2021 were described in Figures 14, 15 & 16 respectively.

Table 9: Range of Kappa value and its agreement

Value of Kappa	Interpretation of agreement
$0.81 \leq K \leq 1.00$	Almost perfect agreement
$0.61 \leq K \leq 0.80$	Substantial agreement
$0.41 \leq K \leq 0.60$	Moderate agreement
$0.21 \leq K \leq 0.40$	Fair agreement
$0.0 \leq K \leq 0.20$	Slight agreement
$K < 0.0$	Poor agreement

Source (Landis and Koch, 1977)

Accuracy

	Water	Irrigated land	Grazing land	Water hyacinth	Wetland
Accuracy					
Producer	0.985	0.6764706	0.947	1	0.9411765
User	1	0.9583333	0.9132653	0.6666667	0.8988764
Overall Accuracy	0.9434698				
KIA	0.9163847				

Classes

Figure 14: Accuracy assessment of the classified image of 2017

Accuracy

	Water	Water Hyacinth	Wetland	Irrigated land	Grazing Land
Accuracy					
Producer	1	1	1	1	0.9577465
User	0.9948980	1	0.9933333	0.9615385	1
Overall Accuracy	0.9933185				
KIA	0.99				

Classes

Figure 15: Accuracy assessment of the classified image of 2019

Accuracy

	Water	Water Hyacinth	Wetland	Grazing Land	Irrigated Land
Accuracy					
Producer	0.9438202	0.8235294	0.9024390	0.9772727	0.742
User	0.9882353	1	0.8043478	0.9148936	0.8518519
Overall Accuracy	0.9172932				
KJA	0.8873706				

Figure 16: Accuracy assessment of classified image of 2021

4.2. *Eichhornia crassipes* Spatial Invasion from 2017 to 2021

The land-use coverage of 2017 indicated that even if *Eichhornia crassipes* recognizably occurred during 2015 for the first time around Lake Dambal (Survey, 2021), the invasion and expansion were fast particularly in 2021 (Table 10). Though it may have a polluting impact on the water by allowing remains to settle to the bottom (Clayton, 2009; Mangas-Ramírez, & Eli’as-Gutiérrez, 2010), and it affects the livelihood of the societies. It is noticed that the fast expansion of *Eichhornia crassipes* was toward wetland, cropland and grazing land during the period from 2017 – 2019. However, between the years 2019 – 2021; its expansion was towards irrigated and grazing land rather than wetland because of the occurrence of flooding. The extent of wetland and *Eichhornia crassipes* were increased with water in 2021. The second land cover that is a good environment for its establishment is cropland. Recession farming is commonly practiced during the dry season when the water of the lake retreats (Lemma *et al.*, 2017). During the rainy season, the land around the lake is also used for different production of crops and vegetables. Hence, this part of the study area was suitable to expand the *Eichhornia crassipes* and leave the cropland in danger of weed invasion.

Similar studies were conducted by Verma *et al.* (2003) to compare areas covered by *Eichhornia crassipes* on six lakes of India, and similar results were observed. The expansion of *Eichhornia crassipes* is largely toward the peripheral areas of the lake. The weed was more visible in the southwestern, eastern and northern parts of Lake Dambal. This is perhaps related to the sediment delivery of the two rivers (Maqi and Katar) in the western and eastern part of the lake which provides comfortable conditions (nutrients washed down from farmlands and other land covers) for the weed in the lake water, the practice of recession agriculture (crop/vegetable production).

The weed is highly prevalent in tropical and sub-tropical water bodies, particularly freshwater bodies as saline water is not suitable for its establishment (Mangas-Ramirez and Elias-Gutierrez, 2010), where water nutrient concentrations are often high due to agricultural runoff, deforestation and insufficient wastewater treatment (Villamagna and Murphy 2010). Its increasing invasion may also be related to the rise in temperature level due to climate change in the surrounding areas of the lake due to deforestation and human intervention (Rodriguez-Gallego *et al.*, 2004; Hellman *et al.* 2008; Rahel and Olden, 2008). The expansion of *Eichhornia crassipes* may also be attributable to its ability to outcompete native vegetation and phytoplankton and the absence of consumers found within its native range such as *Neochetina* *Eichhornia* Warner and *Neochetina* *bruchii* Hustache (Wilson *et al.*, 2005; Villamagna and Murphy, 2010; Tang *et al.*, 2019). However, this requires further investigation. Generally, the summary of the extent changes due to *Eichhornia crassipes* expansion from 2017 up to 2021 is described in Table 10.

Table 10: Change extent of *Eichhornia crassipes* expansion from 2017 to 2021.

Class name	2017 to 2019		2019 to 2021		2017 to 2021	
	Area		Area		Area	
	Ha	%	ha	%	ha	%
Grazing land	-228.27	-0.42	-796.95	-1.53	-1025.22	-1.95
Irrigated land	-213.34	-0.44	-741.45	-1.41	-954.79	-1.85
Wetland	-123.61	-0.23	+289	+0.55	+165.39	+0.32
Water	+532.81	+1.03	+996.6	+1.9	+1529.41	+2.93
<i>Eichhornia crassipes</i>	+32.41	+0.06	+252.77	+0.49	+285.18	+0.55



Figure 17: *Eichhornia crassipes* expansion around Lake Dambal (picked on 23/4/2021)

Even if *Eichhornia crassipes* expansion was increasing, the communities and other government & non-governmental organizations were tried to control its expansion. Different communities & organizations were involved in manual removal of *Eichhornia crassipes* from Lake Dambal (Figure 18 & 19). However, the efforts to control the expansion of *Eichhornia crassipes* were inadequate. Due to that it expanding in to different land uses quickly.



Figure 18: Manual control of *Eichhornia crassipes* expansion (ATJK office of Climate Change & Emergency, 2021)



Figure 19: Organizations involved in the removal of *Eichhornia crassipes* (ATJK Office of Climate Change & Emergency, 2021)

4.3. Response Rate

This section explained the summary of the number of households who participated in the study regarding the designed sample size. Out of 414 (100%) respondents, 406 (98.1%) respondents were returned their responses. But only 8 (1.9%) of respondents were doesn't return their response. Therefore, this shows that the response was good and thus can fit for data validation.

Table 11: The response return rates

Predicted number of sample size	Percentage	Number of Sample return	Percentage	Missing	Percentage
414	100	406	98.1	8	1.9

4.4. Demographic Characteristics of Respondents

To discover the demographic characteristics of the respondents; questionnaires were developed and asked the respondents to describe their gender, age, educational status, marital status, household size (family size), and by extension, the respondent's livelihood. The results were analyzed in frequency counts and percentages. These all-demographic characteristics were stated in their contribution to the study.

4.4.1. Gender and Age Composition

The sex composition was one of the demographic characteristics of the respondents. As stated in Table 12, 74.9% of respondents were male and 25.1% were female. So that, the majority (almost three-fourth) of respondents were male. This implies that in the area there are many male-headed respondents when compared with female-headed respondents. Therefore, *Eichhornia crassipes* have much effect on male-headed respondents than female-headed respondents in the study area.

Regarding age composition, 17.3% of the respondents were between the age of 15 – 24 years, 45.3% of the respondents were between the age of 25 - 44 years, 29.3% of respondents were between 45 - 64 years and 8.1% of respondents were above 65 years. Most of the respondents were aged between 25 – 44 years and 45 – 64 years. This implies that *Eichhornia crassipes* has much affected the respondents between the age of 25 – 44 and 45 – 64 years. Because I thought that the respondents between these ages are mature and they have the ability and potential to work different activities by depending on Lake Dambal. Due to this, *Eichhornia crassipes* has highly affected on those respondents between specified age than others.

Table 12: Sex and age composition of the respondents

Category		Frequency	Percent
Sex	Male	304	74.9
	Female	102	25.1
Age	15 - 24 Years	70	17.3
	25 - 44 Years	184	45.3
	45 - 64 Years	119	29.3
	Above 65 Years	33	8.1
Total		406	100

Source: Own survey (2021)

4.4.2. Educational Status

Educational status was another characteristic of sample respondents. Based on the data stated in Table 13, 28.3% of the respondents cannot read and write (illiterate), 29.1% of respondents were learned from Grade 1 – 4, 22.7% of respondents were attained Grade 5 - 8 while 14.8% of the respondents were attained secondary & preparatory school and finally, 5.2% of respondents had

the certificate of Diploma or Degree. This indicated that the majority of respondents in the study area can read and write. So, they are considered educationally better to understand about the problem and impact of *Eichhornia crassipes* have on their livelihoods.

Table 13: Educational status of the respondents

Educational Status	Frequency	Percent
Illiterate	115	28.3
Grade 1 – 4	118	29.1
Grade 5 – 8	92	22.7
Grade 9 – 12	60	14.8
Certificate	21	5.2
Total	406	100.0

Source: Own survey (2021)

4.4.3. Marital Status

Marital status was the other characteristic of sample respondents used to describe the impact of *Eichhornia crassipes* on respondents' livelihood. Therefore, respondents were asked about their marital status and the results were described in Table 14. Out of the total sample respondents, 406 (100%); 16.0% of the respondents were single, 75.8% of the respondents were married, 2.5% of respondents were divorced, 3.7% and 2.0% of the respondents were the widow and widowed respectively. Therefore, in the area, *Eichhornia crassipes* has mainly affected the married respondents, because most of those married respondents are engaging their livelihood by depending directly on Lake Dambal.

Table 14: Marital status of the respondents

Category	Frequency	Percent
Single	65	16.0
Married	308	75.8
Divorced	10	2.5
Widow	15	3.7
Widowed	8	2.0
Total	406	100.0

Source: Own survey (2021)

4.4.4. Family Size

Determining the family size of respondents was taken as an important characteristic to understand the effect of *Eichhornia crassipes* on livelihoods. Regarding the household size; 16.0% of respondents were single (not married), 24.4% of respondents had a household size between 2 - 4 members, 42.1% of respondents had a household size between 5-7, whereas 17.5% of respondents had household members above 7. This indicates that almost half of the respondents had a household size between 5 – 7 members. This implies that in the study area the livelihood of the household depending on Lake Dambal was large in their family. So *Eichhornia crassipes* have affected the livelihoods of households with larger members.

Table 15: Household size of Respondents

Family size	Frequency	Percent
One	65	16.0
2 – 4	99	24.4
5 – 7	171	42.1
Above 7	71	17.5
Total	406	100.0

Source: Own survey (2021)

4.4.5. Respondents Livelihood Activity

It was also necessary to describe the respondents' livelihood activities they engaged directly from Lake Dambal. So, the impacts of *Eichhornia crassipes* on the livelihood activities of the respondents were determined. The results from Table 16 indicated that; 42.1% of the respondents were irrigators, 14.8% of respondents were fishermen, 6.4% of respondents were water transporters (boat drivers) and 12.6% of respondents were *Typha latifolia* harvester (local name 'Awwaaree'). But only 24.1% of respondents were working other activities like trade, daily labor and rainfall depended on agriculture. Hence, a large proportion of the population (75.9%) have a direct association with the Lake for their livelihood. While 24.1% of the respondents were engaged others, means they were not directly depending on Lake Dambal. This implies that in the area the majority of the population are facing the impact of *Eichhornia crassipes* on their livelihoods.

Table 16: Respondent’s livelihood type

Livelihood types	Frequency	Percent
Irrigator	171	42.1
Fisherman	60	14.8
Boat driver	26	6.4
Tall grass harvester	51	12.6
Total	308	75.9
Others	98	24.1
Grand-total	406	100.0

Source: Own survey (2021)

4.5. History of *Eichhornia crassipes* in and the Surround of Lake Dambal

4.5.1. Observation of *Eichhornia crassipes*

Respondents were asked the question, ‘Did you observe *Eichhornia crassipes* in and around Lake Dambal? Therefore, most of the respondents were observed *Eichhornia crassipes* around Lake Dambal and only 9.6% of the respondents were not observed. The results in Table 17 described that most of the respondents even those whose livelihood is not directly dependent on Lake Dambal were knew and observed *Eichhornia crassipes*.

Table 17: Respondent’s opinion regarding *Eichhornia crassipes* observation

Did you observed <i>Eichhornia crassipes</i> in and around Lake Dambal?	Frequency	Percent
Yes	367	90.4
No	39	9.6
Total	406	100.0

Source: Own survey (2021)

Next to the above question, respondents were asked, ‘The year when *Eichhornia crassipes* was first observed’? Accordingly, 4.4% of respondents were replied that *Eichhornia crassipes* was first observed around Lake Dambal between 2000 – 2003, 9.0% of respondents were said that they observed *Eichhornia crassipes* between 2004 – 2006, 61.6% of respondents were replied that they observed *Eichhornia crassipes* around Lake Dambal between 2007 – 2009 and 25.0%

of respondents were responded that *Eichhornia crassipes* was first observed in the area after 2010.

The majority of respondents were replied that *Eichhornia crassipes* was first observed around Lake Dambal between 2007 – 2009. Specifically, in 2007 they observed *Eichhornia crassipes* for the first time around Lake Dambal.

Table 18: Year of *Eichhornia crassipes* observed

Year in Ethiopian Calendar	Frequency	Percent
2000 – 2003	16	4.4
2004 – 2006	33	9.0
2007 – 2009	226	61.6
After 2010	92	25.0
Total	367	100.0

Source: own survey (2021)

4.5.2. Mechanism of *Eichhornia crassipes* Came into Lake Dambal

Besides their first time of observation, respondents were asked by what mechanism and from where *Eichhornia crassipes* was originally coming to Lake Dambal. All respondents were agreed that *Eichhornia crassipes* came to Lake Dambal from Lake Qoqa, but the difference is only the mechanism it came to the Lake Dambal. The results in Table 19 indicated that; 0.8% of the respondents replied that the weed came to Lake Dambal by animals including birds, 16.3% replied it was come by flood, 12.5% replied it came by Boat, 20% replied that it was come by nets, 10.4% responded that it was come by air, 1.6% of respondents were said it was come by tourists, 2.2% were said it was come by pollutant from the horticultural company that found near Lake Dambal and finally 36.2% of respondents were replied that *Eichhornia crassipes* was come by the excavator. Generally, the majority of respondents were reacted that *Eichhornia crassipes* was come to Lake Dambal by excavators drilled irrigation canals around Lake Qoqa and later it came to around Lake Dambal.

According to information gathered from respondents, *Eichhornia crassipes* was introduced into Lake Dambal between 2007 – 2009 specifically in 2007 by the excavator. Most of the respondents said that “excavators came from the area around Lake Qoqa to drill irrigation canals around Lake Dambal. At that time, it was brought with the seed or living plant of

Eichhornia crassipes to our Lake. Others were said “the fishing nets used by fishermen on Lake Dambal were mainly coming from Lake Qoqa, so that the seed of *Eichhornia crassipes* came with the nets.

Similar studies discovered that in Ethiopia, *Eichhornia crassipes* was first reported about 60 years ago in Lake Qoqa and the Awash River (Firehun *et al.*, 2013). *Eichhornia crassipes* infestation is now distributed in many water bodies of the country from these water bodies (Firehun *et al.*, 2014). Therefore, *Eichhornia crassipes* in and around Lake Dambal was came from Lake Qoqa mainly by excavators, flood and nets.

Table 19: Mechanism of *Eichhornia crassipes* came to Lake Dambal

Category	Frequency	Percent
Excavator	133	36.2
Nets	73	20.0
Flood	60	16.3
Boat	46	12.5
Air	38	10.4
Pollutant from horticultural company	8	2.2
Tourists	6	1.6
Animals including birds	3	0.8
Total	367	100.0

Source: Own survey (2021)

Table 20: Cross-tabulation of livelihood & mechanism of *Eichhornia crassipes* came

Mechanism	Perception of the mechanism of <i>Eichhornia crassipes</i> came					Total
	Irrigator	Fisherman	Boat driver	Tallgrass harvester	Others	
Animals including birds	2	0	0	1	0	3
Flood	22	10	0	12	16	60
Boat	18	5	7	7	9	46
Nets	31	26	5	8	3	73
Air	25	2	2	4	5	38
Tourists	1	2	1	2	0	6
Pollutant from horticultural company	6	0	0	0	2	8
Excavator	66	15	11	17	24	133
Total	171	60	26	51	59	367

Source: Own survey (2021)

The majority of participants in each livelihood including those who were engaged in other activities except fishermen; replied that the mechanism that *Eichhornia crassipes* came from Lake Qoqa to Lake Dambal was by an excavator (Table 20). For further test whether there is a relationship between respondent' livelihood (occupation) and the mechanism of *Eichhornia crassipes* came, a Chi-square, (χ^2) test was used and the result was stated in Table 21. The Chi-square test indicated that the p-value is 0.001 which is less than 0.05 (the alpha level associated with a 95% confidence level). The χ^2 test result shows that the respondents' livelihoods and the mechanism of *Eichhornia crassipes*' came to Lake Dambal were dependent on each other. That means there is a statistically significant relationship between respondents' livelihood and perception of the mechanism of *Eichhornia crassipes* came.

Table 21: Chi-Square Tests for the mechanism of *Eichhornia crassipes* came.

Category	Value	df	P-value
Pearson Chi-square	46.008	21	.001
Likelihood ratio	50.200	21	.000
N of valid cases	308		

Source: Own survey (2021)

4.5.3. Season of *Eichhornia crassipes* Infestation

It was discovered that the season of *Eichhornia crassipes* infestation became critical. The *Eichhornia crassipes* infestation became critical in the area between the season of summer and spring with mostly being the summer season as stated by 316 (86.1%) of respondents (Table 22). This was followed by the spring season 35 (9.5%) of respondents. The majority of respondents were agreed that *Eichhornia crassipes* infestation became critical during the rainy season. The weed *Eichhornia crassipes* was densely distributed to some areas of irrigated land. Because in the area during the summer season of the 2020 year; there was much amount of rain, as a result, flooding has occurred. Many of the population were displaced from their home and some irrigated lands close to the lake were occupied by water and *Eichhornia crassipes*.

Akinyemeju, (1987) has pointed out that *Eichhornia crassipes* spreads faster during the rainy season due to the reduced salinity within the water bodies, and reduces during the dry season because of increased salinity. Similarly, another study conducted in Wonji-Shoa; indicated that *Eichhornia crassipes* coverage was positively correlated with rainfall (RF), Nitrogen,

Phosphorus, Potassium and temperature (T), and negatively correlated with the depth of the water bodies and altitude (Firehun, 2017). This means that *Eichhornia crassipes* coverage is increasing during the rainy season (summer) and decreasing in a place where water depth and elevation are high.

Therefore, *Eichhornia crassipes* was critical during the summer season. But another study stated that, during the dry season, *Eichhornia crassipes* cover is almost 100% (Moyo, 2013). This implies that *Eichhornia crassipes* is more expanded in the winter season. Based on the result obtained and observation, it is possible to conclude that *Eichhornia crassipes* is highly expanded into neighboring areas during the summer season. The responses given by respondents regarding to the season of *Eichhornia crassipes* infestation became critical is described in Table 22.

Table 22: Season of *Eichhornia crassipes* infestation critical

Seasons	Frequency	Percent
Spring	35	9.5
Winter	10	2.7
Autumn	6	1.7
Summer	316	86.1
Total	367	100.0

Source: Own survey (2021)

4.6. Impact of *Eichhornia crassipes* on Livelihood of Community

Because of its rapid growth and mat formation, *Eichhornia crassipes* have a range of detrimental effects on the livelihoods of the communities. The dense mats disrupt socioeconomic and subsistence activities for example ship and boat navigation restricted access to water for irrigation, fisheries, and tourism (Ndimele *et al.*, 2011; Patel, 2012).

4.6.1. Impact of *Eichhornia crassipes* on Irrigation

This section is attempted to establish the influence of *Eichhornia crassipes* on irrigation activities around Lake Dambal. To describe the impact of *Eichhornia crassipes* on irrigation, some questions were prepared and asked the respondents. The respondents have answered the question, is *Eichhornia crassipes* affecting irrigation activity? The results were presented in Table 23; all of the respondents were agreed that *Eichhornia crassipes* harm irrigation activities. This implies that all respondents (particularly Irrigators) were aware of *Eichhornia crassipes*

impact on their irrigation activity. So, the results were tabulated in frequency counts and percentages in Table 23.

Table 23: Perception on whether *Eichhornia crassipes* have impacts on irrigation

Is <i>Eichhornia crassipes</i> affecting irrigation activity	Frequency	Percent
Yes	171	100.0
No	0	0.0
Total	171	100.0

Source: Own survey (2021)

The respondents (particularly irrigators) were also asked the question ‘what are the impacts of *Eichhornia crassipes* on irrigation activities?’ The results were presented in Table 24. It showed that; Many of the respondents (95.3%) were replied that *Eichhornia crassipes* affect irrigation activities by blocking an irrigation canal and absorbed water used for irrigation, but only 4.7% of respondents were responded that *Eichhornia crassipes* affects through causing sediment deposition irrigated land & it growing to irrigated land.

Another study conducted in Wonji-Shoa agreed that *Eichhornia crassipes* causes wastage of water through excessive evapotranspiration that would otherwise be used for irrigation in Wonji (Firehun, 2007). The estimated water loss due to this weed from the highly infested water were ranged between 393,660 to 2,945,160 m³. This amount of water could irrigate an additional 31.12 to 232.84 ha of land. Other reports also said that the weed reduces the flow of water through irrigation canals by 40% – 95% (Jones, 2009). According to Chapungu *et al.* (2018), laboratory experiment in 14-day indicated that *Eichhornia crassipes* covered water surfaces lose more water through transpiration than *Eichhornia crassipes* free water surfaces

Table 24: Impacts of *Eichhornia crassipes* on irrigation

What are impacts of <i>Eichhornia crassipes</i> on Irrigation	Frequency	Percent
Block irrigation canals/pipes	72	42.1
Reduces the quantity of water used for irrigation	91	53.2
Causes for sediment deposition	3	1.8
It covers irrigated land	5	2.9
Total	171	100.0

Source: Own Survey (2021)

About the adverse effects of *Eichhornia crassipes* in farming (irrigation) activities of the area, respondents were revealed that many farmers engaged in hand removal of the weed repeatedly left behind their regular farming. During their participation they received no financial or in-kind

compensation for their time from the government or other bodies. Another impact of the weed on the farm land, was the area occupied by the weed could not be used for crop production. The study's findings also assessed the distribution of *Eichhornia crassipes* on irrigated land. Now, some households whose farm land found around the lake, faced further invasion of the weed especially during summer season because more *Eichhornia crassipes* pushed by water storm and covered farm land. Based on observation the weed expanded and occupied the farm lands which close to the lakeshore. This implies that *Eichhornia crassipes* expansion increased in the lake and adjacent farmlands. It clearly shows the pressing threats of the weed on the livelihood of the people.

In the study area some of farm (irrigated) lands were occupied and invaded by *Eichhornia crassipes*. During data collection, the researcher was observed sometimes the distributed *Eichhornia crassipes* in irrigated land. When I asked the residents of the area; they said that, “during the summer season of 2020 G.C there was much amount of rain and as a result flooding was occurred. So that, *Eichhornia crassipes* was distributed in to irrigated lands with flood.”

Respondents were asked to answer whether their lands were occupied by *Eichhornia crassipes*. The results were described in Table 25. From the total respondents (irrigators) that their lands occupied by *Eichhornia crassipes*, all of respondents were said that less than one hectare of their lands were covered and taken by *Eichhornia crassipes*.

Table 25: Irrigated land covered by *Eichhornia crassipes*

Magnitude of irrigated land	Frequency	Percent
Less than one ha	25	100.0
Two ha	0	0.0
Three ha	0	0.0
Over four ha	0	0.0
Total	25	100.0

Source: Own survey (2021)

***Eichhornia crassipes* and Irrigation Productivity**

The respondents were also asked the question regarding to whether *Eichhornia crassipes* have impacts on productivity of crops or vegetables they produced? From the total irrigators (171); 168 (98.2%) were replied that *Eichhornia crassipes* has impacts on the productivity of irrigation and only 3 (1.8%) of irrigators were said that *Eichhornia crassipes* has no impacts on irrigation.

Table 26: Perception on Irrigation productivity after *Eichhornia crassipes* infestation

Is there a change on irrigation productivity after <i>Eichhornia crassipes</i> infestation?	Frequency	Percent
Yes	168	98.2
No	3	1.8
Total	171	100.0

Source: Own survey (2021)

Finally, respondents were asked the question regarding to the change in productivity of irrigation after *Eichhornia crassipes* infestation. Out of the respondents who said ‘*Eichhornia crassipes* has affected productivity’, all of them (100% or 168) has replied that *Eichhornia crassipes* has decreased the productivity they obtained from irrigation. The study’s finding was agreed with another study that *Eichhornia crassipes* has clogged the irrigation pipes or canals (Chapungu, 2018). This has posed technical difficulties to the irrigation process and has seen a decline in agricultural production. Reduction in agricultural production is a threat to food security in the communities along Lake Dambal. The problem of clogging of irrigation pipes was not reported during the *Eichhornia crassipes* free period. This shows that *Eichhornia crassipes* in Lake Dambal pose problems for agricultural production and may contribute to food insecurity.

Despite the clogging of irrigation pipes, *Eichhornia crassipes* has been reported by communities along the Lake to be influencing water loss from the Lake. Winter water shortages are closely linked to the invasion of the *Eichhornia crassipes*. Excessive water loss from the lake has been regarded as a threat to food security especially in the face of climate change.

A one-way analysis of variance (ANOVA) was also calculated to explain the differences in the perception of the respondents (irrigators) on the effect of *Eichhornia crassipes* on irrigation activities. The results were presented in Table 27.

Table 27: ANOVA on the effect of *Eichhornia crassipes* on irrigation.

Variation	Sum of Squares	df	Mean Square	F	P-value
Between Groups	.135	3	.045	2.679	.049
Within Groups	2.812	167	.017		
Total	2.947	170			

KEY: df - degrees of freedom

The results in Table 27 shows that $F(3,167) = 2.679$ this means p-value of 0.049 which is less than alpha value at 0.05 (α -value at 5%). This implies that *Eichhornia crassipes* has a significant impact on the irrigation activity of the societies.

4.6.2. Impact of *Eichhornia crassipes* on Fishing

Fisheries are an important part of food security and nutrition, particularly for many poor people in developing countries (Adewolu and Adoti, 2010; Tesfaye and Teferi, 2017). Felegeselam (2003) and Petra *et al.* (2009) indicated that the Lake Dambal ecosystem had the economical benefit for the residents of the shoreline of Lake especially for fishermen and Small-Scale Irrigation Users (SSIU). The fishermen got their main household income by catching fish and selling for the local fish wholesale merchants or by selling directly to the market. Small Scale Irrigation Users (SSIU) also were getting economical benefit from ecosystem services of Lake Dambal and its shoreline by producing cereal crops, vegetables and fruit which they sold in the market. According to Seyoum (2016), the mean number of fish produced per year from Lake Dambal is 2,524 Kg, with a minimum and a maximum number of fishes produced per year were 504 and 16,800 Kg respectively. The fishery of the lake is a year-round source of subsistence food and income for many poor households in the region (Endebu *et al.*, 2015). Even if this Lake is serving the societies as a source of income, *Eichhornia crassipes* expansion is becoming high and affecting the livelihood activity like fishing. Some questions regarding fishing activity and *Eichhornia crassipes* impact were prepared and asked the sampled households.

4.6.2.1. Effects of *Eichhornia crassipes* on fishing equipment

Respondents were tried to explain the effects of *Eichhornia crassipes* on fishing equipment. So, the effects are; Access to sites becomes difficult when weed infestation is present, loss of fishing equipment often results when nets or lines become tangled in the root systems of the weed.

Similarly study by Asmare (2017) indicated that fishers turn back to the landing site after they lost a lot of extra fuel and labor with no or with a minimum catch.

Each branch of *Eichhornia crassipes* becomes attached to the fishing net, and when the fishers pull their fishing net during fishing it becomes damaged. Besides repairing the damaged fishing net, fishers invest considerable time in detaching *Eichhornia crassipes* parts (branches) from gillnet after catching or fish. Some fishermen respondents said that ‘*we experience loss of fishing gear, time-wasting during fishing and difficult in movement, and even sometimes prevent people from fishing*’. All these lead to a reduction in fish catch and subsequent loss of livelihood.

4.6.2.2. Effect of *Eichhornia crassipes* Expansion on Fishing Activities

Respondents were asked to contribute their views on the effect of *Eichhornia crassipes* on fishing. From the results in Table 28, all of the respondents (fishermen) were replied that *Eichhornia crassipes* has negative impacts on fishing activity. This indicated that all fishermen were understood the problem *Eichhornia crassipes* has on fishing activities.

Table 28: Perception of the impact of *Eichhornia crassipes* on fishing.

Is <i>Eichhornia crassipes</i> affecting fishing	Frequency	Percent
Yes	60	100.0
No	0	0.0
Total	60	100.0

Source: Own survey (2021)

Heavy infestations by *Eichhornia crassipes* make fishing very difficult, or impossible (FAO. 2002). Similarly, Mailu’s (2001) report stated that for the individual fisherman, the hyacinth mats reduced their catch by covering fishing grounds, delaying access to markets due to loss of output, increasing fishing costs due to the time and effort spent clearing waterways, forcing translocation, and causing loss of nets. Besides, some respondents added that “*The weed led to transport barriers on water thus hindering better access to fishing point*”. These are among the many effects reported.

According to Opande *et al.* (2004) when *Eichhornia crassipes* infestation is present, access to fishing sites becomes difficult for riparian communities which rely solely on fishing as their main economic activity. Similarly, a study by Frezina (2013) also reported that *Eichhornia*

crassipes can present many problems for the fishers. But *Eichhornia crassipes* provide a highly complex habitat structure by restricting the growth of other submerged macrophytes. This modification and habitat complexity at the surface of the water is likely affecting fishing.

In severe infestation especially around the shore area, fishing is therefore too much difficult. This results in blockage of fish landing sites and destruction of fishing gear. Hence, as much as *Eichhornia crassipes* is viewed; it has harmed fishing, as it causes difficulty in fishing. Other studies also reported that; if *Eichhornia crassipes* continues in this trend, it can negatively affect the livelihood of fishers in both directions by increasing costs of fishing and reducing the number of fish caught in Lake Tana (Asmare *et al.*, 2016). *Eichhornia crassipes* can also greatly affect fish catch rates because mats of *Eichhornia crassipes* can block access to fishing grounds and clog the eye of the net. A study in Lake Victoria by Bhattacharya *et al.* (2015) also showed fish catch rates decreased by 45% because *Eichhornia crassipes* mats blocked access to fishing grounds, delayed access to markets and increased the cost (efforts and materials) of fishing.

Respondents were also asked to share their views on whether the change in fish catch is as well associated with *Eichhornia crassipes*. From the frequency count stated in Table 29, most of the fishermen respondents (98.3%) were responded that *Eichhornia crassipes* is associated with the change in fish catch. But only 1.7% of fishermen were replied that change in fish catch is not associated with *Eichhornia crassipes* infestation.

Table 29: Perception on fish catch change after *Eichhornia crassipes*

Do you realize a change in the number of fish caught associated with <i>Eichhornia crassipes</i> ?	Frequency	Percent
Yes	59	98.3
No	1	1.7
Total	60	100.0

Source: Own survey (2021)

Regarding to the impact of *Eichhornia crassipes* on the change in the number of fish caught; *Eichhornia crassipes* negatively correlates with the change in the number of fish caught. Then means in heavy *Eichhornia crassipes* infestation, the number of fish caught was becoming less. The study conducted by Terry (1996) reported that fishermen are being troubled by a reduced range of fish species, loss of nets and impeded access. *Eichhornia crassipes* was perceived to

affect fisheries through reduced levels of production, a reduction in species diversity, poor quality of fish, the rising cost of operation resulting in lower-income to fishers and higher prices to consumers (LVEMP, 1995).

According to a study conducted in Lake Victoria by Kateregga and Sterner (2009); *Eichhornia crassipes* blocked breeding, nursery, and feeding grounds for economically important fish species, such as tilapia and Nile perch. Because *Eichhornia crassipes* mats can reduce natural predation and fisheries catchability, leading to increased abundance of certain species; but mats can also exclude certain species from important breeding, nursery, and feeding grounds (Twongo & Howard, 1998).

This study also tried to describe the changes after *Eichhornia crassipes* infestation and the results were summarized in Table 30. So that from fishermen respondents who agreed there was a change in the number of fish caught after *Eichhornia crassipes* infestation (from the result in Table 29); all fishermen respondents were replied that *Eichhornia crassipes* decreases the number of fish catch.

Firehun, (2007) described that there were fish species that disappeared due to *Eichhornia crassipes* infestation from their environment, whereas there were other fish species that could survive well in these conditions. And also, Mailu (2001) reported that due to *Eichhornia crassipes* there were fish species that declined from their living environment. The fish species that declined in the Kenyan section of the lake were 14% of *Oreochromis* (a large genus of tilapia), 37% of *Clarias* (a genus of catfish), and 59% of *Mormyrus* (a genus of bottom-feeding breams). Twongo (1998), also noted that the weed mats sealed off breeding, nursery, feeding, and fishing grounds for various inshore fish species, like tilapia and young Nile perch.

This study is also a framework with studies conducted by Asmare (2017) around Lake Tana. He observed that fishing has been exhausted due to the expansion of the weed. *Eichhornia crassipes* catches the fishing nets and push boats, making it difficult to fish and resulting in reduced fish catches. As fish production weakened, the income of those people whose economic activities rooted in fish production reduced and this would harm the livelihood of the communities around the lake and consequently affect the economy. Solomon (2017) also indicated that the annual fish

production potential in Lake Tana is estimated to be 13000 tons but its current annual production is only about 1000 tons due to *Eichhornia crassipes* infestation in and around Lake Tana.

A serious decline in fish stocks due to the spread of *Eichhornia crassipes* around fish spawning grounds. So, the lake has lost 75% of its fish production. This implies that the *Eichhornia crassipes* invasion is affecting fish production as well fish catch. So, it leads to weakening the income of the people involved in this fishing activity.

Therefore, *Eichhornia crassipes* harmed the change of fish catch, thus causing a loss in fish species and fish stocks. The reduction in fish species and stocks will cause an economic slowdown for fishermen. The results of the Change of fish caught after *Eichhornia crassipes* infestation in the study area are presented in Table 30.

Table 30: Change of fish caught after *Eichhornia crassipes* infestation.

Describe the changes of fish caught?	Frequency	Percent
Increasing	0	0.0
Decreasing	59	100.0
Total	59	100.0

Source: Own Survey (2021)

A one-way analysis of variance was also carried out to discover the differences in the perception of the fishermen respondents on the effect of hyacinth on fishing activities. The results were presented in the ANOVA Table 31.

Table 31: ANOVA on the effect of *Eichhornia crassipes* on fishing.

Variation	Sum of Squares	df	Mean Square	F	P-value
Between Groups	.183	1	.183	13.292	.001
Within Groups	.800	58	.014		
Total	.983	59			

KEY: df-degrees of freedom

From the results stated in Table 31, $F(1,58) = 13.292$ that means $p\text{-value} = 0.001$ which is less than alpha value at 0.05. This shows that there is a significant effect of *Eichhornia crassipes* on fishing activity around Lake Dambal. Therefore, all of the participants saw a heavy impact of *Eichhornia crassipes* on fishing activity, particularly difficulty in catching of fish. The findings

are supported with those of Center *et al.* (2002) report that *Eichhornia crassipes* invasions reduce light for submerged plants hence depleting oxygen, altering the composition of invertebrate communities, impacting fisheries, and displace native plants and wildlife, and increasing sediment loading. Other related research findings also brought out the same feedback that *Eichhornia crassipes* causes severe problems to fishermen in the riparian communities.

When weed infestation is present, access to fishing sites becomes difficult for riparian communities which rely solely on fishing as their main economic activity (Munjigni, 2012).

4.6.3. Impact of *Eichhornia crassipes* on Transportation on Water

Eichhornia crassipes is physically interfering with water transport, communication and access. Infestations are increasing in Ethiopia, creating a range of problems including restricted access (Aweke, 1994). Penfound and Earle, (1948) found that *Eichhornia crassipes* grows rapidly, forming expansive colonies of tall, interwoven floating plants. It blankets large water bodies, creating impenetrable barriers and obstructing navigation (Gowanloch and Bajkov, 1948; Zeiger, 1962).

Respondents were asked whether *Eichhornia crassipes* has impacts on transportation on water and the results were described in Table 32. According to the results in Table 32, all of the respondents (boat drivers) were knew and agreed about the impact of the weed on navigation on the water. This implies that all of the respondents (boat drivers) were aware of the impacts of *Eichhornia crassipes*.

Table 32: Perception on *Eichhornia crassipes* impact on navigation on water

Is <i>Eichhornia crassipes</i> affecting navigation?	Frequency	Percent
Yes	26	100.0
No	0	0.0
Total	26	100

Source: Own survey (2021)

Boat driver respondents were tried to describe the impact of *Eichhornia crassipes* on transportation on water. So, *Eichhornia crassipes* has affected the boat's navigation by blocking the ways of the boat and hindering navigation on the water. The results in Table 33 realized that 84.6% of respondents were replied that, *Eichhornia crassipes* has affected navigation through blocking boat ways and hindering navigation and 15.4% of respondents were answered

Eichhornia crassipes has affected the boats by damaging the bottom of boats as it collides with *Eichhornia crassipes*. This study agreed with that *Eichhornia crassipes* has blocked waterways and hamper navigation, affecting boats by leading to the damage of hulls as they collide with objects under *Eichhornia crassipes* mats (Ezama, 2019).

According to Asmare, (2017) reports *Eichhornia crassipes* is risky to the boat because the weed slow down the speed of the boat and we couldn't escape from a hippopotamus. Other studies also reported that *Eichhornia crassipes* mats prevent means of approaching harbors and jetties and clodding rivers and canals. *Eichhornia crassipes* is becoming a problem as it also prevents the passage of marine vessels (Ndinwa *et al.*, 2012). Within the Delta region of Nigeria, operations of several boat harbors and maritime workers have been limited as the aquatic plant blocks facilities and damages boat ramps causing overheating in boat motors. *Eichhornia crassipes* decreases the use of facilities for boat rentals and other maritime businesses (Ndinwa *et al.*, 2012).

Table 33: Perception regarding the impacts of *Eichhornia crassipes* on boat navigation

What are the impacts of <i>Eichhornia crassipes</i> on navigation	Frequency	Percent
Block boat ways and hinder navigation	22	84.6
Damage the bottom of boats as it collides with <i>Eichhornia crassipes</i>	4	15.4
Total	26	100.0

Source: Own survey (2021)

In Nigeria, Alimi and Akinyemiju (1991) showed that the costs of fuel and repairs to boats on infested waterways were approximately three times that on un-infested waterways. Economic losses also result from interference with recreational uses of water bodies (Gopal, 1987; Amy, 2009). *Eichhornia crassipes* as it invades forming blankets over large bodies of water and creating impenetrable barriers and obstructing water transportation. The thick mats also block access to recreational areas and affect the economies of communities that depend on it (Wassie *et al.*, 2007). This observation was supported by the information obtained from boat driver respondents that many young and adults in the study area were organized and engaged in water transportation services. However, due to barriers by *Eichhornia crassipes*, many of these people

stopped working and became idle. Therefore, the *Eichhornia crassipes* invasion became an obstacle for water transportation and affected the livelihood of people engaged this activity.

Table 34: Perception regarding *Eichhornia crassipes* associated with transporting time

Transportation time after <i>Eichhornia crassipes</i> infestation	Frequency	Percent
Increased	26	100.0
Decreased	0	0.0
Total	26	100.0

Source: Own survey (2021)

A one-way analysis of variance was also carried out to discover the differences in the perception of the respondents (boat driver) on the effect of *Eichhornia crassipes* on transportation on water. The ANOVA results were presented in Table 35.

Table 35: ANOVA on impacts of *Eichhornia crassipes* on transportation on water

Variation	Sum of Squares	df	Mean Square	F	P-value
Between Groups	4.297	3	1.432	3.197	.043
Within Groups	9.857	22	.448		
Total	14.154	25			

KEY: df-degrees of freedom

From results described in Table 35 indicated that, $F(3,22) = 3.197$ which means $p\text{-value} = 0.043$ this is less than alpha value at 0.05. This indicated that there is a significant effect of *Eichhornia crassipes* on water transportation. The results, therefore, show that *Eichhornia crassipes* harm water transportation.

4.6.4. Impact of *Eichhornia crassipes* on *Typha latifolia* Harvesting

Typha latifolia (common name ‘broadleaf cattail’) is a cosmopolitan occurring in wetlands through most temperature zones in North America, Europe and Asia, and many subtropical areas. It has also invaded the few regions where it is not native, e.g., Oceania, South-East Asia and other parts of the world. It forms dense populations under suitable conditions, often as monocultures excluding other species of vegetation (Holm *et al.*, 1997). *Typha latifolia* were used by many indigenous peoples (Turner, 1981; Gott, 1999). Historically *Typha latifolia* has been used throughout the world as building material, bedding, basketry, shoemaking, rope and paper manufacture and within a variety of herbal applications (Ramsey, 1981; Mitich, 2001). Still today *Typha latifolia* are having a large potential and new uses are envisioned, such as biomass production or as a modern-day food crop (Marton, 1975; Pratt *et al.*, 1980; Ciria *et al.*,

2005). Other relatively new uses include water purification, bioremediation (Alvarez *et al.*, 2008; Chan and Choi, 2009; Moore *et al.*, 2009), as a bioindicator of pollution. *Typha latifolia* is cultivated as an ornamental. It is often sold commercially and planted for wildlife habitat and in wetland restoration.

Typha latifolia have different importance for local peoples in the study area. It is used for making roofs of the houses, feeding for animals, and making pillows and mattresses. The communities in the study area were harvesting and selling *Typha latifolia* to make roofs for houses and mattresses & pillows.

The expansion of *Eichhornia crassipes* in and around Lake Dambal is affecting the activity of harvesting *Typha latifolia* from the wetland. To discover the effect of *Eichhornia crassipes* on *Typha latifolia* harvesting, respondents were asked to state whether *Eichhornia crassipes* has impacts on *Typha latifolia* harvesting. All of the respondents were agreed that *Eichhornia crassipes* has negative impacts during harvesting *Typha latifolia* activities from Lake Dambal. A similar study reported that *Eichhornia crassipes* highly invaded and destroyed a variety of grass and plant species grown in the wetland. The grazing land has been substantially reduced, creating a serious challenge for the community engaged in cattle breeding (EBI, 2019).

The respondents whose livelihood was *Typha latifolia* harvesting were tried to list the impacts of *Eichhornia crassipes* on it. From the results described in Table 36, *Eichhornia crassipes* has negatively affected the activity by preventing the growth of the *Typha latifolia* densely, controlling harvesting *Typha latifolia* well and blocking the way to out the harvested *Typha latifolia* from the water.

Table 36: Impact of *Eichhornia crassipes* on *Typha latifolia* harvesting activity.

What are the impacts of <i>Eichhornia crassipes</i> on <i>Typha latifolia</i> harvesting	Frequency	Percent
It prevents the growth of this plant species densely	3	5.9
It controls harvesting in a good manner	11	21.6
It blocks the way to out harvested grasses from the lake	37	72.5
Total	51	100.0

Source: Own survey (2021)

During data collection, respondents were described the effects of *Eichhornia crassipes* on their activity by said “after *Eichhornia crassipes* was densely populated in the area around Lake, we can’t harvest *Typha latifolia* in much amount as before. Therefore, the amount of *Typha latifolia* (broadleaf cattail) harvested was decreased due to the expansion of *Eichhornia crassipes*, but its cost was increased on the market.”



Figure 20: The harvested *Typha latifolia* & prepared for sell

A one-way analysis of variance was also carried out to discover the differences in the perception of the respondents on the effect of *Eichhornia crassipes* on harvesting *Typha latifolia* activity. The results are present in the ANOVA Table 37.

Table 37: ANOVA on impacts *Eichhornia crassipes* on *Typha latifolia* activity.

Variation	Sum of Squares	df	Mean Square	F	P-value
Between Groups	6.126	4	1.532	4.239	.005
Within Groups	16.619	46	.361		
Total	22.745	50			

KEY: df-degrees of freedom

From results stated in Table 37, $F(4,46) = 4.239$ that means $p\text{-value} = 0.005$ this is less than alpha value at 0.05. The results, therefore described that there is a significant effect of *Eichhornia crassipes* on *Typha latifolia* harvesting activity.

4.7. The Benefit of *Eichhornia crassipes*

Eichhornia crassipes has limited beneficial uses (Wassie *et al.*, 2014). Using the *Eichhornia crassipes* as animal fodder is a traditional practice in many areas of Asia, including China, Bangladesh, Indonesia, India, Malaysia, the Philippines, and Thailand. In Malaysia, fresh *Eichhornia crassipes* is cooked with rice bran and fishmeal and mixed with copra meal as feed for pigs and ducks. However, it is suited to all animals as *Eichhornia crassipes* has high water and mineral content (Henrylito, 2009).

The local communities around Lake Dambal are worried about the invasion of *Eichhornia crassipes* to their shore farm and grazing lands. As different studies conducted in many countries even though *Eichhornia crassipes* causes various socio-economic and environmental problems, there are experiences that the plant has been turned to useful purpose before it became a problem (Hailu, 2018). In Lake Dambal *Eichhornia crassipes* has some beneficial purposes but it was not considered as useful. The questions regarding to the benefits of *Eichhornia crassipes* were asked respondents who observed & knew *Eichhornia crassipes* around Lake Dambal and the results were presented in Table 38. Accordingly, 27.0% of the respondents indicated that *Eichhornia crassipes* has benefits mainly for cattle feed, 52.9% of the respondents indicated they didn't understand that *Eichhornia crassipes* has important means they replied that *Eichhornia crassipes* has not important and 20.1% of the respondents mentioned they didn't know whether it is important or not. Therefore, it is possible to generalize that in the area around Lake Dambal most peoples were not aware of using *Eichhornia crassipes*.

Table 38: Perception on whether *Eichhornia crassipes* has benefits

Is <i>Eichhornia crassipes</i> having benefits in your area?	Frequency	Percent
Yes	99	27.0
No	194	52.9
I don't know	74	20.1
Total	367	100.0

Source: Own survey (2021)

Cattle were grazing *Eichhornia crassipes* during the dry season when there is no grass. The study by Wassie *et al.*, (2014) reported that Cattle graze the *Eichhornia crassipes* when there is no grass in the dry period.

Dereje *et al.*, (2017) also mentioned that expansion of *Eichhornia crassipes* and its competition with the native species submerging grasses and other native species becomes devastated. These affect a lot of cattle, directly and indirectly, dependent on the grass. And also shore area floras which would be important for fish breeding grounds and livestock forage sources in the vicinity become damaged. So many farmers in the study area faced a shortage of cattle feed due to mostly absence of common grazing ground in the locality. The cattle were forced to use *Eichhornia crassipes* for feed.

This study is also supported by a study conducted by Ikiara (1999) that the weed has potential real economic value and it has been reported for instance that the weed can produce biogas energy, purify water contaminated by raw sewage, produce manure (compost preparation) and produce a substratum for the nourishment and breeding of some fish species. This indicated that besides its adverse effects, the *Eichhornia crassipes* plant could be turned to useful purposes. This implies that in the study area the possible benefit of *Eichhornia crassipes* was not well recognized by the local communities which could have been taken as a way to manage the expansion of the weed. The possible benefits of *Eichhornia crassipes* were asked the respondents around Lake Dambal and the results were described in Table 39. Accordingly, 69.7% of respondents were replied that water has used for animal fodder, 30.3% were responded *Eichhornia crassipes* has used for the germination of vegetables. But, none of the respondents said *Eichhornia crassipes* was used for compost preparation. This indicated that all respondents were not aware of the importance of *Eichhornia crassipes* for the preparation of compost.

However, studies reported that *Eichhornia crassipes* has the potential to be used as green or compost manure, which can directly be applied to the soil as green manure (Darius *et al.*, 2016). The *Eichhornia crassipes* plant is optimal for compost by mixing it with animal manure, ash and soil after it's been dried in the sun. The plant's lipids, proteins, fats starches and sugars are broken down by microbial decomposition left to compost by the action of warm climates. This

process produces compost free of pathogens. The compost when applied to the soil, increases the fertility and quality of the soil improving crop yield.

Darius *et al.*, (2016) established that manure of organic origin is more effective in improving soil quality than chemical manure. The shredded leaves and stalk of *Eichhornia crassipes* plants make a reliable quality of compost within a specified time when mixed with 8.1 ratios of cow dung and with curd. Liquid manure made from the *Eichhornia crassipes* contains 3.72% nitrogen and 2.86% potassium, which can be used as macronutrient fertilizer. Composting *Eichhornia crassipes* using a biogas production plant has the advantage that methane emissions, which represent a potent greenhouse gas, can be collected and are not emitted to the atmosphere.

A similar study conducted by Ogunlade (2002) reported that *Eichhornia crassipes* has some beneficial uses of the invasive aquatic plant such as: used as animal and fish feed which is a good source of protein, a good source of raw materials for paper and board manufacture, produce biogas which is an ideal clean energy source for electricity generation and cooking, used for manufacturing fertilizer (compost preparation) as the root extract aids in crop production and active carbon from the *Eichhornia crassipes* when combined with Zinc Chloride ($ZnCl_2$), is suitable for decolonization use in pharmaceutical industries and general application.

The study conducted by Su *et al.*, (2018) was also agreed with the above information in that the fresh biomass of *Eichhornia crassipes* contains a crude protein value of 2.38%, crude fat of 0.27%, the crude fiber of 0.91% and nitrogen-free extract of 3.7% by mass. Despite the above, the dry matter of *Eichhornia crassipes* has abounding nutrients of which crude protein is 10 - 20%, which can be used as both roughage and protein feed. The leaves of *Eichhornia crassipes* after they have been cut and dried, have a crude protein value of 15.58% to 19.97%, crude fat of 1.33% to 1.85%, the crude fiber of 13.74% to 11.04% and ash content of 16.04% to 14.97%.

Table 39: Benefits of *Eichhornia crassipes* around Lake Dambal

What are the benefits of <i>Eichhornia crassipes</i> in your area?	Frequency	Percent
Animal fodder	69	69.7
Mulching (Germination)	30	30.3
Preparation of compost	0	0.0
Total	99	100.0

Source: Own survey (2021)

***Eichhornia crassipes* as animal fodder**

Respondents were asked the questions like the way of livestock grazing *Eichhornia crassipes*, change on livestock after they fed the weed and change on production of milk after livestock (cattle) grazed *Eichhornia crassipes*. From the total respondents who agreed that *Eichhornia crassipes* was used for animal fodder, all were replied that in the study area livestock grazing *Eichhornia crassipes* on their own just like grass without cutting and adding other things like salts to it. The way livestock particularly cattle grazing *Eichhornia crassipes* is described in Figure 20.

Table 40: The way of livestock grazing *Eichhornia crassipes*

How livestock were feeding <i>Eichhornia crassipes</i>	Frequency	Percent
They are grazing on their own just like grass	69	100.0
They are feeding by cutting & then adding others like salts	0	0.0
Total	69	100.0

Source: Own survey (2021)



Figure 21: *Eichhornia crassipes* grazing by cattle (Dechasa and Abate, 2020)

From the results stated in Table 41, most of the respondents (82.6%) replied that livestock was lost their body weight after they fed *Eichhornia crassipes*. But only 2.9% of respondents were replied that livestock has been gained body weight after they fed *Eichhornia crassipes* and 14.5% of respondents didn't know whether livestock gained or lost body weight. Therefore, even if *Eichhornia crassipes* was used as a source of animal fodder in the study area, livestock

became lost their body weight after they fed *Eichhornia crassipes* as compared to before. A similar study conducted by Osumo (2001) showed that *Eichhornia crassipes* has a negative impact on livestock feed because it contains too much silica, calcium oxalate, potassium and too little protein. Therefore, these leads to reducing grazing potential, and have a negative impact on animal health, milk and meat quality and economic reduction on the livestock sector of the country. Feed containing 30% more *Eichhornia crassipes* can reduce weight gain by over 90% (Henrylito, 2009).

According to Enyew *et al.*, (2020) feeding of *Eichhornia crassipes* caused gut bloating and continuous diarrhea on livestock. The stalk tissues of *Eichhornia crassipes* contain intercellular spaces filled with air which is the principal factor for the bloating of ruminant guts and continuous diarrhea to the livestock feeding from the weed (Enyew *et al.*, 2020). It also increases the intensity of breeding of leech and other internal parasites in the lake and associated marshlands which contributed to losing bodyweight and death of livestock.

Table 41: Perception on livestock’s body weight after they fed *Eichhornia crassipes*.

How is the livestock change on their weight after they grazed <i>Eichhornia crassipes</i>	Frequency	Percent
Gain	10	14.5
Loss	57	82.6
I don’t know	2	2.9
Total	69	100.0

Source: Own survey (2021)

According to the results in Table 42, most respondents were agreed that *Eichhornia crassipes* was reducing the production of milk after cattle fed it. According to EBI (2019), mats of *Eichhornia crassipes* affect livestock production by suppressing submerging grasses (hippo grass) which feed lots of cattle for the surrounding inhabitants. Therefore, there was highly decrease in their milk and milk by-products because of the devastation of this weed.

Table 42: Perception on change of milk production

How is the production of milk after cattle fed <i>Eichhornia crassipes</i> ?	Frequency	Percent
Increased	10	14.5

Decreased	57	82.6
I don't know	2	2.9
Total	69	100.0

Source: Own survey (2021)

CHAPTER FIVE

CONCLUSIONS & RECOMMENDATIONS

5.1. Conclusions

The *Eichhornia crassipes* expansion in the year between 2017 up to 2021 within 2 years intervals and its impact on livelihood activities was analyzed. Accordingly in 2017, 2019, and 2021 years; the expansion of *Eichhornia crassipes* was mostly in the northern, eastern, and southeastern parts of the lake. The extent of *Eichhornia crassipes* was increased from year to year from that 32.51 to 64.92 ha in 2017 to the 2019 year and then increased to 317.69 ha in the 2021 year. So that the change detection of *Eichhornia crassipes* expansion in terms of extent from 2017 to 2021 years was +285.18 ha (+0.55%). The results have shown that its coverage and expansion were increased in fast towards peripheral land uses especially on irrigated and grazing lands, which is dangerous for the socio-economy of the societies and sustainability of the lake.

The impact of *Eichhornia crassipes* on livelihoods depending on Lake Dambal was analyzed. It was summarized that; the weed has both negative and positive impacts in the study area. The negative impacts of *Eichhornia crassipes* were so adverse and described as follows; blockage of waterways, hampering irrigation, fisheries, hindering navigation on the water, unemployment among the fishermen, destruction of the fishing nets, impeding of boat movements, and deteriorating of *Typha latifolia* harvesting. Generally, *Eichhornia crassipes* has affected the major livelihoods of societies that engaged by depending on Lake Dambal. *Eichhornia crassipes* also affect grazing and other agricultural activities by forming impenetrable thickets and hindering movements of humans and animals, destroying and replacing natural biodiversity, inaccessibility of drinking water by livestock, and impairing recreational activities. However, the benefits of *Eichhornia crassipes* includes the source of the animal fodder, mulching, and making artifacts (mattress).

5.2. Recommendations

If the expansion of *Eichhornia crassipes* continues, the whole lake will be invaded by weed to an extent greater than +285.18 ha (+0.55%). This may put the socio-economic status of the communities like the health status of the society, their livelihood activities, and environmental condition at risk. This means that *Eichhornia crassipes* reduces the growth and development of the communities in economically, socially, politically & environmentally in the study area particularly and sustainable development of the country in general. So, all concerning bodies including communities, stakeholders, government, and non-government organizations should have to take the following recommendation (solution) to manage the expansion of *Eichhornia crassipes* and to overcome the problems on their livelihoods.

- An action plan should be developed to carry out an awareness on the expansion of *Eichhornia crassipes* and its impact.
- Involve the stakeholders, local and riparian communities in the removal of the *Eichhornia crassipes* from Lake Dambal.
- Control both point and non-point sources of pollution that inter into the lake. These are important in managing *Eichhornia crassipes* expansion. Because the pollution may have nutrients like phosphate and nitrate. These nutrients increase the *Eichhornia crassipes* expansion into water bodies.
- The communities in the study area should have to change the *Eichhornia crassipes* into economic advantage like preparation of compost.
- The government should fund an adequate financial budget to remove (if not reduce) *Eichhornia crassipes* expansion from Lake Dambal.
- The government and stakeholders should find and import machines used to remove *Eichhornia crassipes* from Lake Dambal.

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Appendix I: Questionnaires

Jimma University
College of Social Sciences and Humanities
Department of Geography and Environmental Studies

Questionnaire to be filled by local communities

Dear Respondents

This questionnaire is preparing to collect data for research going to undertake on “*Detection of Eichhornia crassipes Expansion Using Geospatial Techniques: A Case of Lake Dambal*”. The information will be used only for academic purposes. Thank you in advance!

Instruction: Dear respondent please encircle your response for each question and write also your responses to the questions on the spaces provided.

Section One: Background Information of Respondent.

S/N	Respondents' information	Responses
1.	Gender	1. Male 2. Female
2.	Age	1. 18-30 years 2. 31-55 years 3. >55 years
3.	Educational level	1. Illiterate 2. 1-4 3. 5-8 4. 9-12 5. Post certificate (diploma and above)
4.	Marital status	1. Single 3. Divorced 2. Married 4. Widow 5. Widowed
5.	Household size	1. One 2. 2 - 4 3. 5 - 7 4. > 7

Section Two: General Information

6. Do you observe *Eichhornia crassipes* (*Emboch*) around Lake Dambal? 1. Yes 2. No

7. If 'yes', when did you first observe *Eichhornia crassipes* around the lake?

1. 2000 – 2003 2. 2004 – 2006 3. 2007 – 2009 4. After 2010

8. By what mechanism did *Eichhornia crassipes* come to the lake?

1. Animals Livestock 2. Flood 3. Boat Vehicles 4. Net 5. Air 6. Tourist 7. Pollutant from horticultural company 8. Excavator

9. Which season has been critical in *Eichhornia crassipes* expansion?

1. Spring 2. Winter 3. Autumn 4. Summer

10. Is your livelihood activity dependent on Lake Dambal? 1. Yes 2. No

11. If 'yes', which livelihood activity?

1. Irrigation 2. Fishing 3. Transportation on water 4. Harvest *Typha latifolia*

Section Three: Livelihood Effects of *Eichhornia crassipes*

A. If your livelihood is fishing activity on question number (11), answer questions on number 12 – 15.

12. Is *Eichhornia crassipes* affect fishing? 1. Yes 2. No

13. If 'yes', on the question number 12, what are the impacts of *Eichhornia crassipes* on fishing?

1. Reduces the fish stocks 2. The difficulty of access to fishing sites 3. Destruction of fishing gear 4. Blocks the way of the boat to catch fish 5. Delaying access to markets

14. Do you realize a change in the number of fish caught associated with *Eichhornia crassipes*? 1. Yes 2. No

15. If 'yes', explain the change of fish caught? 1. Increased 2. decreased

B. If your livelihood is irrigation on question number (11), answer questions number 16 - 21.

16. Is *Eichhornia crassipes* affect irrigation activity? 1. Yes 2. No

17. If 'yes', what are the impacts of *Eichhornia crassipes* on irrigation?

1. Block irrigation canals/pipes 2. Reduces the quantity of water used for irrigation 3. Increase sediment deposition along the shore of the lake and irrigated land 4. It covers irrigated land
18. Has your irrigated land been invaded by *Eichhornia crassipes*? 1. Yes 2. No
19. If 'yes', on the above question, how many hectares of your farmland have been invaded by this weed? 1. Less than 1 hectare 2. Two hectares 3. Three hectares 4. More than 4 hectares.
20. Is there any change in the production of crops/vegetables you produced due to the presence of *Eichhornia crassipes* in your farm plots? 1. Yes 2. No
21. If yes, please estimate the change of crops/vegetables you produced after the infestation of *Eichhornia crassipes*? 1. Increased 2. Decreased
- C. If your livelihood is transportation on the water on question number (11), answer questions number 22 – 25.**
22. Is *Eichhornia crassipes* affect water transportation? 1. Yes 2. No
23. If 'yes', what are the impacts of *Eichhornia crassipes* on water transportation?
 1. Block boat ways and hinder navigation 2. Damage the bottom of boats as it collides with *Eichhornia crassipes* 3. Shortening the lifespan of boats 4. Others; specify

24. Is there a time difference during transportation after the *Eichhornia crassipes* expansion? 1. Yes 2. No
25. If 'yes', explain the change? 1. Increased 2. Decreased.
- D. If your livelihood is harvesting *Typha latifolia* on question number (11), answer questions number 26 – 28.**
26. Is *Eichhornia crassipes* has impacts on harvesting *Typha latifolia* activity? 1. Yes 2. No
27. If 'Yes' on the above question, what are the impacts of it on this activity?
 1. It prevents the densely growing of *Typha latifolia* 2. It controls harvesting very well
 3. It blocks the way to out the harvested *Typha latifolia* from wetland and water.

28. After *Eichhornia crassipes* infestation, how was the *Typha latifolia* harvested per day?
1. Increased 2. Decreased

Section four: Benefits of *Eichhornia crassipes*

29. Does *Eichhornia crassipes* have any advantage in the local area? 1. Yes 2. No
30. If 'yes' on the above question, what are the advantages of *Eichhornia crassipes*?
1. Source of animal fodder 2. Compost preparation 3. Mulching (Germination) 4. Others

If you said 'Source of animal fodder' on question number 30, answer questions from numbers 31 – 34.

31. How livestock were fed *Eichhornia crassipes*?
1. They graze just like grass from ground 2. Cut and add other things like salt.
32. After livestock fed *Eichhornia crassipes*, is there change on their bodies?
1. Yes 2. No 3. I don't know
33. If 'Yes' on the above question, explain the change? 1. Gain body weight 2. Lose bodyweight
34. What about the change in milk production after milk-produced cattle fed *Eichhornia crassipes*? 1. Increased 2. Decreased

If you said 'Compost preparation' on question number 30, answer the questions from numbers 35 to 39.

35. Did you prepare compost from *Eichhornia crassipes*? 1. Yes 2. No
36. If 'Yes' on the above question, when you prepared compost; it is only from *Eichhornia crassipes* or do you add other things? 1. Only from *Eichhornia crassipes* 2. Other things were added to *Eichhornia crassipes*
37. If 'you added other things on the above question, what is it?
1. Cattle held 2. Crop residues 3. Others specify: _____
38. If this compost is added to maize, onion, tomato...; its production increased or decreased?
1. Increased 2. Decreased

39. Are these crops sowed with Compost tolerated the diseases?

1. Yes 2. No 3. I don't know

Appendix II: Translated Questionnaires In To Afan Oromo

Yuunivarsiitii Jimmaatti

Kolleejjii Saayinsii Hawwaasaa fii Namummaa

Dippaartimantii Ji'ograafii fi Qu'annoo Naannoo

Gaaffilee hawaasa naannichaatin guutaman

Hawaasa kabajamoof

Gaaffileen armaan gadiitti qophaa'an kun qorannoo mata-dureen isaa “*Detection of Eichhornia crassipes Expansion Using Geospatial Techniques: A Case of Lake Dambal*” jedhu yoo ta’u, odeeffannoon isinirraa sassabamus kaayyoo barnootatiif qofa akka ta’e kabajaanin isin beeksisa. Yeroo keessan aarsaa waan gootaniif galatoomaa!

Qajeelfama: Gaaffilee tokkoon tokkoof deebii keessan itti maruun deebisaa.

Kutaa 1: Odeeffannoo duuba hawwaasaa

Tartiiba lakk.	Gaaffilee	Deebii
1.	Saala	<ul style="list-style-type: none"> • Dhiira • Dhalaa
2.	Umrii	<ul style="list-style-type: none"> • Waggaa 15 - 24 • Waggaa 25 - 44 • Waggaa 45 - 64 • Waggaa 65 ol
3.	Haala barnootaa	<ul style="list-style-type: none"> • Hin baranne • Kutaa 1 – 4 • Kutaa 5 – 8 • Kutaa 9 – 12 • Diploomaa ykn Digrii
4.	Haala Fuudhaf heerumaa	<ul style="list-style-type: none"> • Qophaa • Fuudhe ykn heerumte • Hiike ykn hiikte • Abbaan warraa kan irraa du’e • Haati warraa kan irraa duute
5.	Baay’ina maatii	<ul style="list-style-type: none"> • Tokko

		<ul style="list-style-type: none">• 2- 4• 5- 7• 7 ol
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Kutaa 2: Odeeffannoo Waliigalaa

6. Naannawa Hara Dambaliitti aramaa imbocii (bocee) jedhamuu argitee beektaa?

1. Eeyyen 2. Lakki

7. Yoo ‘Eeyyen’ jette gaafii lakk. 6 irratti, yeroo jalqabaaf yoom (bara) kam argite?

1. 2000 - 2003 2. 2004 - 2006 3. 2007 - 2009 4. 2010 - as

8. Aramaa imbociin maalidhaan gara Hara Dambaliitti dhufe jette yaaddaa? 1. Bineeldotaan 2. Lolaadhan 3. Jalbaadhan 4. Marabaan 5. Qilleensan 6. Daawwattootan 7. Xuurawaa Kaampaanii habaaboo fi lafa jallisii keessaa bahuun

9. Aramaan imbocii (boceen) waktii kam sirritti babal’ataa?

1. Waktii Birraa 2. Waktii Bonaa 3. Waktii Arfaasaa 4. Waktii Gannaa

10. Hojiin ati hojjattu Hara Dambal irratti kan hirkateedhaa?

1. Eeyyen 2. Lakki

11. Yoo ‘Eeyyen’ jette gaafii lakk. 11 irratti, gosa hojii kamiidha?

1. Jaallisiidha 2. Qurxummiin qaba 3. Geejjiba bishaanirraati 4. Awwaaren haama

Kutaa 3: Dhiibbaa Imbociin (Boceen) Hojii Hawwaasaa Irratti Qabu

A. Dhiibbaa Imbociin Hojii Qurxummii Irratti Qabu

Yoo hojiin kee ‘Qurxummii qabuu’ ta’e gaafii lakk. 11 irratti, gaaffilee lakk. 12 – 15 jiran deebisi.

12. Aramaa imbociin hojii qurxummii qabuu irratti dhiibbaa qabaa?

1. Eeyyen 2. Lakki

13. Yoo ‘Eeyyen’ jette gaafii lakk. 12 irratti, dhiibbaa akkamii?

1. Akka qurxummiin hin baay’anne ykn wal hin horre godha 2. Iddoo qurxummiin jirtu argachuun ni ulfaata (dawoo ta’aaf) 3. Ciccituu marabaa fi caccabuu maxxanqoo fida 4. Jalbaatti karaa cufa 5. Hanqina dhiyeessii fida

14. Jijjiiramni baay’ina qurxummii guyyaatti qabamuu dhufaatii aramaa imbociin walqabata jettee yaaddaa?

1. Eeyyen 2. Lakki

15. Yoo ‘Eeyyen’ jette gaafii lakk. 15 irratti, jijjiirama akkamii?

1. Ni dabale 2. Ni hir'ate

B. Dhiibbaa Imbociin Hojii Jallisii Irratti Qabu

Yoo hojiin kee 'jallisii' ta'e gaafii lakk. 11 irratti, gaaffilee lakk. 16 – 21 jiran deebisi.

16. Aramaa imbociin (boceen) hojii jallisii irratti dhiibbaa qabaa?

1. Eeyyen 2. Lakki

17. Yoo 'Eeyyen' jette gaafii lakk. 17 irratti, dhiibbaa imbociin jallisii irratti qabu maalidha?

1. Bo'oo (Ujummo) jallisii cufa 2. Hamma bishaanii jallsiif oolu xuuxa (hir'isa)
3. Lafa jallisii naannoo haraatti argaman irratti biyyeen harama akka kuufamu godha
4. Aramaa imbociin lafa jallisii uuwwisa

18. Lafti Jallisii kee aramaa imbociin uuwwifamee ykn fudhatamee?

1. Eeyyen 2. Lakki

19. Yoo 'Eeyyen' jette gaafii lakk. 18 irratti, lafa jallisii heektaara meeqatu imbociin fudhatame?

1. Heektaara tokkoo gadi 2. Heektaara lama 3. Heektaara sadii 4. Heektaara afurii ol

20. Sababa aramaa imbociitin oomishnii jallisii ati oomishtu jijjiirama qabaa?

1. Eeyyen 2. Lakki

21. Yoo 'Eeyyen' jette gaafii lakk. 20 irratti, oomishni ni dabale moo ni xiqqaate.

1. Ni dabale 2. Ni hir'ate

C. Dhiibbaa Imbociin Geejjiba Bishaanirraa Irratti Qabu

Yoo hojiin kee 'Geejjiba Bishaanirraa' ta'e gaafii lakk. 11 irratti, gaaffilee lakk. 22 – 25 jiran deebisi.

22. Aramaa Imbociin geejjiba bishaanirraa irratti dhiibbaa ni qabaa?

1. Eeyyen 2. Lakki

23. Yoo 'Eeyyen' jette gaafii lakk. 23 irratti, dhiibbaa Imbociin geejjiba bishaanirraa irratti qabu maalidha?

1. Karaa jalbaan irra deemuu cufuun deemsa dhoorka 2. Qaama jalbaatti nam'uun miidhaa jalbaarratti fida 3. Umrii jalbaa gabaabsa

24. Yeroo geejjiba bishaanirraa iddoo murtaahaa tokko gahuuf, Imbociin osoo hin dhufin duraa fi erga dhufee booda garaagarummaan sa'aatii jiraa? 1. Eeyyen 2. Lakki

25. Yoo 'Eeyyen' jette gaafii lakk. 25 irratti, garaagarummaa akkamii?

1. Ni dabale 2. Ni hir'ate

D. Dhiibbaa Imbociin Hojii Awwaaree Haamuu Irratti Qabu

Yoo hojiin kee ‘Awwaaree Haamuu’ ta’e gaafii lakk. 11 irratti, gaaffilee lakk. 26 – 28 jiran deebisi.

26. Aramaa Imbociin hojii awwaaree haamuu irratti dhiibbaa ni qabaa?

1. Eeyyen 2. Lakki

27. Yoo ‘Eeyyen’ jette gaafii lakk. 27 irratti, dhiibbaa akkamii?

1. Awwaaren hedduminaan akka hin biqille godha 2. Haalan akka hin haamne dhoorka
3. Karaa cufuun awwaaree haamame akka hin baasne dhoorka

28. Erga Imbociin dhufee hammi awwaaree guyyaatti haamtanii ni dabale moo ni hir’ate?

1. Ni dabale 2. Ni hir’ate 3. Hin beeku

Kutaa 4: Faayidaa Imbocii

29. Naannoo keessanitti Imbociin faayidaa qabaa? 1. Eeyyen 2. Lakki 3. Hin beeku

30. Yoo ‘Eeyyen’ jette gaafii lakk. 29 irratti, faayidaan imbocii maal fa’a?

1. Nyaata horiif oola 2. Kompoostii qopheessuf oola

A. Yoo ‘Nyaata Horiif Oola’ jette gaafii lakk. 30 irratti, gaaffilee lakk. 31 – 35 jiran guuti.

31. Horiin, kotte duudaa dabalatee imbocii akkamitti nyaatu?

1. Lafaa gad jedhanii dheedu 2. Mummuraniifit wantoota akka ashaboo waliin nyaatu

32. Horiin imbocii yoo nyaatan jijjiiramni qaama isaanirratti mul’ataa?

1. Eeyyen 2. Lakki 3. Hin beeku

33. Yoo ‘Eeyyen’ jette gaafii lakk. 33 irratti, jijjiirama akkamii? 1. Ni furdatu 2. Ni huqqatu

34. Saawwan elmaman (jabbii hoosisan) irratti hoo oomishni aannanii maal fakkaata?

1. Ni dabala 2. Ni hir’ata 3. Hin beeku

B. Yoo ‘Kompoostii qopheessuf oola’ jette gaafii lakk. 30 irratti, gaaffilee armaan gadii guuti.

35. Imbocii irraa Kompoostii qopheessitee? 1. Eeyyen 2. Lakki

36. Yoo ‘Eeyyen’ jette gaafii lakk. 35 irratti, Yommuu kompoostii qopheessitan, imbocii qofarraa qopheessitu moo waan biraa itti dabaltu? 1. Imbocii qofa 2. Ni daballa

37. Yoo ‘Ni daballa’ jette gaafii lakk. 36 irratti, maal fa’a?

1. Dikee horii 2. Hambaa midhaanii 3. Kan biroo: _____

38. Kompoostin imbocii, qonna kan akka boqolloo, qullubbii, timaatimaa fi kkf yommuu xaa’eessuuf dabaltan oomishni ni dabala moo ni xiqqaata?

1. Ni dabala 2. Ni xiqqaata

39. Dhukkuba hoo ni dandamataa? 1. Eeyyen 2. Lakki 3. Hin beeku

Appendix III: Observation Guide List

Replication Number: _____ Observation date/time: _____

No.	Observations around Lake Dambal	Yes	No	Comments
1.	Occurrence of <i>Eichhornia crassipes</i> in & around Lake Dambal			
2.	The expansion of <i>Eichhornia crassipes</i> to other land uses			
3.	Livelihood activities depending on Lake Dambal			
4.	Fish catching activity			
5.	Irrigation activity			
6.	Water transportation activity			
7.	<i>Typha latifolia</i> harvesting activity			
8.	Presence of fishermen catching fishes			
9.	Presence of boats and boat drivers			
10.	Irrigated land along the shore of the lake Dambal			
11.	Grazing land along the shore of the Lake Dambal			
12.	Benefit of <i>Eichhornia crassipes</i>			
13.	Cattle grazing <i>Eichhornia crassipes</i>			
14.	Other benefits of <i>Eichhornia crassipes</i>			

Appendix IV: Letter From Jimma University



Appendix V: Procedure of Sample Size Determination

$$n = \frac{N}{1+(N*e^2)}$$

Where n is the sample size; N is the population size; and e is the level of precision (acceptable margin of error) at 95% confidence interval ($5\%=0.05$).

$$n_0 = \frac{32976}{1 + (32976 * (0.05)^2)}$$

$$n_0 = \frac{32976}{83.44}$$

$$n_0 = 395$$

Appendix VI: Accuracy Assessment

i. Accuracy of 2017 image

Error Matrix based on Samples

User Class \ Sample	Water	Irrigated land	Grazing land	Water hyacinth	Wetland
Confusion Matrix					
Water	198	0	0	0	0
Irrigated land	0	23	1	0	0
Grazing land	3	10	179	0	4
Water hyacinth	0	0	1	4	1
Wetland	0	1	8	0	80
unclassified	0	0	0	0	0
Sum	201	34	189	4	85
Accuracy					
Producer	0.985	0.6764706	0.947	1	0.9411765
User	1	0.9583333	0.9132653	0.6666667	0.8988764
Hellden	0.9924812	0.7931034	0.9298701	0.8	0.9195402
Short	0.985	0.6571429	0.869	0.6666667	0.851
KIA Per Class	0.9756930	0.6605918	0.9143758	1	0.9288291
Totals					
Overall Accuracy	0.9434698				
KIA	0.9163847				

ii. Accuracy of 2019 image

Error Matrix based on Samples

User Class \ Sample	Water	Water Hyacinth	Wetland	Irrigated land	Grazing Land
Confusion Matrix					
Water	195	0	0	0	1
Water Hyacinth	0	9	0	0	0
Wetland	0	0	149	0	1
Irrigated land	0	0	0	25	1
Grazing Land	0	0	0	0	68
unclassified	0	0	0	0	0
Sum	195	9	149	25	71
Accuracy					
Producer	1	1	1	1	0.9577465
User	0.9948980	1	0.9933333	0.9615385	1
Hellden	0.9974425	1	0.9966555	0.9803922	0.9784173
Short	0.9948980	1	0.9933333	0.9615385	0.9577465
KIA Per Class	1	1	1	1	0.9502052
Totals					
Overall Accuracy	0.9933185				
KIA	0.99				

iii. Accuracy of 2021 image

User Class \ Sample	Water	Water Hyacinth	Wetland	Grazing Land	Irrigated Land
Confusion Matrix					
Water	84	0	1	0	0
Water Hyacinth	0	14	0	0	0
Wetland	0	0	37	2	7
Grazing Land	2	3	2	86	1
Irrigated Land	3	0	1	0	23
unclassified	0	0	0	0	0
Sum	89	17	41	88	31
Accuracy					
Producer	0.9438202	0.8235294	0.9024390	0.9772727	0.742
User	0.9882353	1	0.8043478	0.9148936	0.8518519
Hellden	0.9655172	0.9032258	0.8505747	0.945	0.7931034
Short	0.9333333	0.8235294	0.74	0.8958333	0.6571429
KIA Per Class	0.9174375	0.8137255	0.882	0.9648520	0.7127818
Totals					
Overall Accuracy	0.9172932				
KIA	0.8873706				