SPATIO-TEMPORAL ANALYSIS OF WATER HYACINTH USING GEOSPATIAL TECHNOLOGY: A CASE STUDY OF LAKE ABAYA, ETHIOPIA.

Dinkineh Abebe

A Thesis Submitted to the Department of Geomatics Engineering,

School of Civil Engineering and Architecture

Presented in Partial Fulfilment of the Requirements for the Degree of Master's in Geo-Informatics Engineering

Office of Graduate Studies

Adama Science and Technology University

August, 2021

Adama, Ethiopia

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Advisor: Tilahun Erduno (Ph.D.)

Co-Advisor: Mesfin Benti (Ph.D.)

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APPROVAL SHEET

We, the advisors of the thesis entitled "Spatio-Temporal Analysis of Water Hyacinth Using Geospatial Technology: A Case Study of Lake Abaya, Ethiopia." and developed by Dinkineh Abebe Kepeno, here by certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the board of Examiners of the thesis by Dinkineh Abebe Kepeno have read and evaluated the thesis entitled "Spatio-Temporal Analysis of Water Hyacinth by Using Geospatial Technology: A Case Study of Lake Abaya, Ethiopia." and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Geo-informatics Engineering.

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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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Post-graduate Dean	Signature	Date

DECLARATION

I hereby declare that this Master Thesis entitled "Spatio-Temporal Analysis of Water Hyacinth Using Geospatial Technology: A Case Study of Lake Abaya, Ethiopia." is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Name: Dinkineh Abebe Kepeno Signature: **……………………….. ** Date: **………………..**

RECOMMENDATION

we, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled “Spatio-Temporal Analysis of Water Hyacinth Using Geospatial Technology: A Case Study of Lake Abaya, Ethiopia.” prepared under our guidance by Dinkineh Abebe Kepeno submitted in partial fulfillment of the requirements for the degree of Masters of Science in Geo-Informatics Engineering. Therefore, we recommend the submission of a revised version of the thesis to the department following the applicable procedures.

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ACRONYMS AND ABBREVIATIONS

DA	Discriminant Analysis
EMA	Ethiopian Mapping Agency
ENVI	Environmental for visualizing image
ERDAS	Earth Resources Data Analysis System
ESA	European Space Agency
ETM	Enhanced Thematic Mapper
GCP	Ground Control Point
GIS	Geographical Information System
GPS	Global Positioning System
LULC	Land Use Land Cover
LULCC	Land Use Land Cover Classification
MSI	Multispectral Instrument
MSS	Multispectral sensors
NIR	Near Infrared
OLI	Operational Land Imager
RS	Remote Sensing
SPOT	Satellite Probatoire d'Observation de la Terre
USGS	United States Geological Survey

ABSTRACT

The water hyacinth (Eichhornia crassipes) is often regarded as the world's most notorious invasive species. Although its threats and consequences are widely documented, its dispersion is not yet understood. In Southern Ethiopia, Lake Abaya has serious problems related to the alien water hyacinth invasive weed. The water hyacinth develops in and swims over water, rapidly spreading. Using Sentinel-2 MSI data from 2016, 2018, and 2020, this study aimed to map and analyze the Spatio-temporal distribution of invasive water hyacinth in Lake Abaya. The rate of expansion of water hyacinth was measured using Sentinel-2 MSI satellite pictures obtained in December. For the supervised classification of satellite pictures and accuracy assessment, training samples were obtained. Prior to classification, picture preprocessing and enhancement were performed. Maximum likelihood classification algorithms were used to study the spread and distribution of the water hyacinth. The classification accuracy assessment result was 90%, 91.55%, 87%, overall accuracy and kappa coefficient of 87.82%, 89.44%, 86%, for the year 2016, 2018 and 2020 respectively. The results showed that in 2016, water hyacinth coverage was small, with an estimated 2303.49 ha (1%) of the research area covered. In 2018, the coverage of the weed was 5227.27 ha (3%) and after two years, the coverage of water hyacinth in 2020 was 5942.62 ha (4%) of the study area was covered. The results indicated there was a rapid expansion of water hyacinth from 2016 to 2020. Because the weed is rapidly spreading and endangering the water's existence, an adequate intervention mechanism should be implemented as soon as possible.

Keywords: *Water Hyacinth; Lake Abaya; Remote Sensing; GIS; Image Classification*

CHAPTER I: INTRODUCTION

1.1. Background of the study

The water hyacinth (Eichhornia crassipes) is a fast-growing plant is claimed to be indigenous to the Amazon basin (Barret, S. C. H., & Forno. (1982); Piyaboon, O., et al. 2016). It is a plant that poses conservation and socio-economic issues due to its quick growth and horizontal expansion. Streamflow, navigation, and recreational activities have all been known to cause major issues and damage to aquatic ecosystems (Téllez et al. 2008). The water hyacinth is also known for disturbing on marine ecosystems and habitats, particularly by lowering water quality and infecting aquatic species with tropical diseases. The water hyacinth is the most common and harmful aquatic plant species in Africa, where it is categorized as a toxic plant (UNEP, 2013). Threats caused by invasive alien species such as water hyacinths, such as biodiversity, water quality degradation, economic growth, and human well-being, are not easily handled and difficult to reverse (UNEP, 2013).

Water hyacinth was first introduced as a decorative plant in Ethiopia during the 1950s in the Rift Valley Lakes Region, and then spread to the Highland Lakes over time (Firehun, Struike, Lantinga & Taye, 2014; Tegene & Ayele, 2014). It has since been identified as one of the top 10 ecologically dangerous aquatic flowers in the country. It has had a negative impact on the people of the Rift Valley Lakes Region's social, economic, and livelihood conditions, as well as their development efforts (Mengistu et al. 2017). A terrible weed incident has recently been observed on the country's largest lake (Lake Tana) and its surrounding wetlands (Admas et al., 2018). Its existence over the Lake's wetlands was first noticed in 2011 at the entrance of the Megech River, covering approximately 80-100 ha of land along the northern rims of the Lake (Asmare, 2017). The invasion then extended rapidly into the Lake's northeastern catchments, covering over 15% of the northern portions of the lake's coastline areas (Asmare, 2017). According to Tewabe (2015), in 2011 the water hyacinth area coverage was between 80 and 100 ha. A year later, it increased to some 20,000 ha and grew in 2014 to 50,000 ha. The water hyacinth invasion in Ethiopia has had negative economic, ecological, and social impacts.

Recent evidence remarks that the water hyacinth is distributed to Abaya Lake (Emboch on Lake Abaya Prompts Formation of New Committee, n.d.). The water hyacinth, one of the world's worst aquatic weeds that infest rivers, dams, reservoirs, and irrigation channels, first appeared a year ago and now occupies 324 ha of the lake, which is located in Ethiopia's central rift valley, east of the Guge Mountains. As a result,' the alarming rate of water hyacinth expansion prompted the establishment of the committee to conserve the water bodies. Because of the Extending over the wetlands in two west abaya kebeles, water hyacinth covered 187ha of the waterbody in Qorga and 134ha in Albe kebeles (Rift Valley Lakes Basin Authority., 2020). This time, Lake Abaya, which supplies 412 tons of fish per year, with a surface area of 1,162 sq km is at risk, the Lake is 60Kms long and 20Kms wide. It has islands including Gidicho, Welege, Galmaka, and Alkali. It is already posing a significant threat to livestock feed sources, native plant species, fishing activities, water quality, recreation (swimming). It is greatly impacting the balance of the local ecology and biodiversity. All of these issues have an impact on the local communities' socioeconomics and ecology (Shekede et al. 2008).

Moreover, despite huge resources and efforts committed to its control, the water hyacinth has become uncontrollable in Ethiopia (Byrne et al., 2010). Furthermore, the lack of current and precise spatial data makes weed management more difficult. For integrated water resource management, management efforts to date have relied on non-regular, costly, time-consuming, and frequently erroneous surveys (Dube et al. 2017). There is also a need to actively map and track water bodies affected by invasive species, as well as identify areas that have already been affected, in order to develop effective water hyacinth management techniques.

However, to understand the evolution of aquatic weeds, identify affected areas, and assess existing control measures and management actions, reliable and up-to-date information on the geographical distribution of aquatic weeds is required for the success of the national initiatives mentioned above (Shekede et al. 2008). Since then, Geospatial Technologies (Remote Sensing and Geographic Information Systems) have evolved as a more efficient and effective means to identify and map plant species and their changes through time. To control water hyacinth dynamics, spatial data can thus be utilized (Mukarugwiro et al. 2019). The feasibility of using fine spatial resolution imaging to detect, map, and monitor the growth of aquatic weeds has been demonstrated by several scholars (Cheruiyot et al. 2014; Masocha, and Skidmore, 2011; Zhang et al. 2017). Remote Sensing is ideal for monitoring invasive infestations as it offers low cost, high temporal resolution, and fine to medium resolution data (Foody, 2002; Jensen, 2000). So, RS data can advise water managers on the spread of invasive aquatic species (Dube et al. 2017).

There are limitations of these studies in mapping water hyacinth, given the fact that the dynamic and the movement of water hyacinth requires high temporal resolution remote sensing data. However, most of the high temporal data are very broad in terms of spatial data. Multi-sensor remote sensing can thus assist with this aspect. Sentinel-2 MSI satellite sensor, which was recently launched, is thought to give the most ideal primary data sources for repeated monitoring of small or large-scale bodies of water.

1.2. Statement of the Problem

Lake Abaya, one of the Rift Valley basin's lakes, is in danger of becoming covered with water hyacinth. This time, Lake Abaya, which produces 412 metric tons of fish each year, is in danger. The lake is 60 kilometers long and 20 kilometers wide, with a surface area of 1,162 square kilometers.

Despite various measures have taken, because of the Extending over the wetlands in two abaya kebeles. As a first step, according to Gamo Gofa zone ecosystem conservation, biodiversity growth and protection directorate and the weed that covers the lakes edge is being removed by hand, with boats being used to clear it from the center. As a second step, to cut the weed a new machine was donated from Amaga Plc, The machine can chop and grind 5000 square meters of weed every hour (Rift Valley Lakes Basin Authority., 2020). Despite all of these efforts, the amount of weeds in the lake is expanding rather than decreasing.

Various investigations were conducted in the area addressing the weed's rising spread and recommendations for monitoring methods. According to Mengist & Moges (2019), the wide distribution and abundance of water hyacinths have led to decreased water availability and sustainable water biodiversity in Abaya Lake. On the other hand, Mengistu et al., (2017) reported the impact of water hyacinth on macrophyte species assemblage and biodiversity in Lake Abaya, southwestern Ethiopia. By comparing four sites in Lake Abaya, two hyacinths infested and two non-infested, each site consisting of 15 plots. Their result showed that water hyacinth affects the macrophyte community composition, abundance, and diversity negatively. Despite the severity of the growth, little is known about its spatiotemporal distribution, extent, or trend. The water hyacinth's spatial extent and rate of expansion need to be investigated.

The use of high-resolution satellite images and GIS tools is critical in tackling the challenges listed above. Various research have used low resolution remote sensing data to identify invasive alien plant species in the previous. Hence, the classification of water hyacinth using satellite images in GIS is not easy because of the long-time data collection process, slow computer processing capacity, and the need for highly skilled specialists. To resolve these problems, employing the Google map, Google Earth Engine platform application is a simple solution, and it has been employed in several studies.

Therefore, the study contributed to estimating the invaded area by applying multispectral satellite data to the Google Earth Engine platform. It also assisted in monitoring and evaluating the seasonal status of the invasive weed over the lake. Finally, it will help the government and stakeholders employ strategies to limit water hyacinth expansion through lake-level management.

1.3. Objectives

1.3.1. General Objective

The general objective of this study is Spatio-Temporal analysis of Water Hyacinth Using Geospatial Technology a Case Study of Lake Abaya, Ethiopia.

1.3.2. Specific Objectives

- To develop the Land Use Land cover map of Lake Abaya and its surroundings using remote sensing and GIS.
- To analyze the dynamics of water hyacinth of Abaya Lake by using satellite images (for the years 2016, 2018, and 2020).
- To quantify the rate of change dynamic study of water hyacinth coverage of the study area.

1.4. Research questions

- How much is the spatial coverage of water hyacinths at various times?
- What are the coverage changes and patterns of water hyacinth from the year 2016 to 2020?
- What is the growth rate of water hyacinth (Eichhornia crassipes) expansion over the study area?

1.5. Significance of the study

This study provides relevant information about the alarming rate of expansion of water hyacinth and its implications for Lake Abaya, as well as evaluating and analyzing water hyacinth growth and expansion by using geospatial technologies. The study generally gives attention to water hyacinth expansion and its impact on responsible stakeholders and government officials of Lake Abaya.

The findings of this study will provide data for various stakeholders, such as academics, government departments, non-governmental organizations, and other groups.

Accurate and reliable detection and mapping of invasive species such as water hyacinth in freshwater ecosystems provide important spatial and ecological information required for sustainable remedial, eradication, and effective management programs. Important to water resources managers, hydrologists, and policymakers, for sustainable water resources management and planning purposes.

1.6. Scope of the study

The scope of this study is spatially determined to Lake Abaya and its surroundings on the drawback of problem statement mentioned on the above. Thematically, the study focused on Spatiotemporal analyzing of water hyacinth on Abaya Lake, mapping and detecting water hyacinth through the use of sentinel-2 MSI from other land use land cover.

1.7.Limitation of the study

There are certain limitations to this research. As a result, this project had a lot of limitations, from data collection to analysis. Among these constraints, the following are some of them:

Due to the cost and lack of availability of the finest images, which are ideal for detecting water hyacinth, the study's first limitation is the use of a Sentinel 2 imager with a resolution of 10m for land use land cover classification and detecting water hyacinth from other green plants.

The other is that in order to improve accuracy, ground truth and GPS data sampling should be undertaken. Due to the similarity of the spectral signatures of the features, mapping land use and land cover change is difficult during interpretation and image classification.

1.8.Thesis Organization

This thesis is presented in five chapters. The first chapter introduces the proposed topic, Spatio-Temporal analysis of water hyacinth by using geospatial technology: the case study of Lake Abaya, Ethiopia. It also includes the problem statements, research questions, and significances of the study, objectives, delimitations, and limitations of the study. The second chapter is a literature review. This includes the theoretical framework on Spatio-temporal analysis of water hyacinths, such as definition, methods, and empirical framework which includes previous studies related to this study. Afterward, chapter 3 has a closer look at the materials and methods. This chapter gives an overview of the description of the study area, materials used, data analysis methods, and conceptual framework of the study. Results obtained from the data analysis to achieve the objectives of the study follow in chapter 4, together with an interpretation of results and discussion. Chapter 5 is the conclusion and recommendations for future studies based on the result of the study.

CHAPTER II: LITERATURE REVIEW

2.1. Theoretical Framework

2.1.1. Invasive species

Invasive species are organisms found in foreign regions with the ability to reproduce and infiltrate their new environments (Xu et al. 2012) rapidly. Plant invaders are listed among the key pressures that exacerbate biodiversity loss (Genovesi et al. 2015; Rands et al. 2010). This has resulted in accelerated efforts from ecologists, conservationists, and governments, globally to control the further spread of non-native plant species that threaten the ecological integrity of new environments they enter into (Rogers, 2018; Scanes, 2018; Xu et al. 2012). Invasive alien species are primarily introduced to foreign regions by humans, either intentionally or accidentally (Rogers, 2018; Scanes, 2018).

Invasive exotics pose a major threat globally to economies, ecological systems, and societies (Kganyago et al. 2018; Mostert et al. 2017; Patel S, 2012). Genovesi et al., (2015) estimated the overall economic loss of €12 billion in Europe in 2009 due to the encroachment of invasive species. Similarly, the water hyacinth was officially appeared in Ethiopia about 53 years ago in 1965 at Koka reservoir and in the Awash River. Other infestations in the country include Gambela Region, the Blue Nile from just below Lake Tana into Sudan, and Lake Ellen near Alem Tena (Fessehaie R, 2005; Taye et al. 2009). Water hyacinth caused wastage of water through excessive evapotranspiration, recreational use of the aquatic ecosystem, and mechanical damage to hydroelectric systems. It is also responsible for drastic changes in the fisheries communities of water environments and acts as an agent for spreading serious diseases in water bodies (Admas et al., 2017; Balmford A, 2005).

2.1.2. Water Hyacinth

Water hyacinth (Eichhornia crassipes) is a free-floating perennial (or hydrophyte) aquatic weed that originated in the Amazon Basin and has spread fast in many countries throughout Latin America, Africa, Southeast Asia, and the Pacific since 1950 (Patel S, 2012). These plants are among the top 100 most harmful invasive species and the top ten worst weeds in the world, according to the International Union for Conservation of Nature (IUCN) (Patel S, 2012). It is characterized by wide-spreading competencies, extensive dispersal mechanism, rapid reproductive potential, and harsh environment tolerance adaptability (Zhang YY, Zhang DY, 2010).

The water hyacinth (Eichhornia crassipes) is the most hazardous and invasive aquatic weed in the world, including Ethiopia, negatively affecting millions of water resources, fisheries, transportation, and social structures. The water hyacinth was first introduced to the Rift Valley's water bodies 68 years ago, and it is now found in Lake Tana, Lake Abaya, Lake Koka, and the Koka Dam. The water hyacinth's widespread distribution and abundance have resulted in reduced water availability and sustainable water biodiversity in Ethiopian lakes. The expansion of water hyacinth, on the other hand, poses a threat to water biodiversity, socioeconomic development, and human well-being(Negassa Dechassa, 2021).

Water hyacinth reproduces rapidly and creates dense, interlocking mats above water bodies (Figure 1).Water hyacinth can reproduce both sexually and asexually, attributes to its ability to propagate at high rates(Patel , 2012; Villamagna, and Murphy, 2010). The sexual reproduction of water hyacinth is through stolons, while seed dispersal is the asexual reproductive method of this invasive plant (Patel S:, 2012). The presence of the dense water hyacinth mats interferes with waterways, disrupts aquatic ecosystems' functioning, and creates ideal conditions for disease-carrying vectors(Kushwaha, 2012; Perna, C. and Burrows, 2005; Villamagna, A.M. and Murphy, 2010). These cause a disturbance in the everyday economic, social, and ecological activities of water hyacinth-infested waters (Parsons et al., 2001; Perna, C. and Burrows, 2005; Villamagna, A.M. and Murphy, 2010). Such disruptions in water bodies' functioning include decreased boating navigability and access, hindrance of water supply systems and drainage canals, and decreased fish populations(Parsons et al., 2001; Perna, C. and Burrows, 2005; Villamagna, A.M. and Murphy, 2010). Water hyacinth similarly disrupts the ecological processes of water bodies. It decreases dissolved oxygen concentrations and limits phytoplankton's productivity while creating ideal conditions for diseases and exacerbating their carriers (Kushwaha, 2012; Parsons et al., 2001; Villamagna, A.M. and Murphy, 2010)

Lindsey, K. and Hirt (1999) state that water hyacinth harvesting can significantly enhance ecological, economic, and social aspects in communities. The authors list water purification, animal fodder, fertilizer, and paper production as some of the beneficial water hyacinths uses, even though it is an invasive species.

2.1.3. Water hyacinth in Ethiopia

The water hyacinth first appeared in Ethiopia 53 years ago, in 1965, at the Koka reservoir and the Awash River. The Gambela Region, the Blue Nile from just below Lake Tana into Sudan, and Lake Ellen near Alem Tena are among the country's other infestations. (Fessehaie R, 2005; Taye et al., 2009). Water hyacinths' widespread distribution and abundance have resulted in reduced water availability and sustainable water biodiversity in Ethiopian lakes. The expansion of water hyacinth, on the other hand, poses a threat to water biodiversity, socioeconomic development, and human well-being. Water hyacinth in water bodies and nearby areas the local stakeholder negatively impacts the environmental problem, and it's influenced aquatics biodiversity.

Water hyacinth (*Eichhornia crassipes*) is the most dangerous and worst invasive aquatic weed worldwide, including Ethiopia, negatively affecting millions of water resources, fisheries, transportation, and social structure. Water hyacinth was first introduced to the Rift Valley's water bodies 68 years ago, and it is now found in Lake Tana, Lake Abaya, Lake Koka, and the Koka Dam. Water hyacinths' widespread distribution and abundance have resulted in reduced water availability and sustainable water biodiversity in Ethiopian lakes. The expansion of water hyacinth, on the other hand, poses a threat to water biodiversity, socioeconomic development, and human well-being(Negassa Dechassa, 2021).

According to Asmare (2017), In 2011, the presence of water hyacinth in Lake Tana was discovered. It has continued to thrive year after year since its acknowledgment. Even though, over the previous seven years, several bodies, governmental, non-governmental, and local communities have attempted a variety of efforts to fight the spread of the weed in Lake Tana, Lake Abaya, Lake Koka, and the Koka Dam, despite these efforts, it regenerates and expands year after year. Furthermore, it has become harder to stop.

2.1.4. Factors that propagate the sprawl of water hyacinth

Several authors DWAF (2007); Thamaga & Dube (2018); Villamagna, A.M. and Murphy, (2010) have identified the following factors as the natural drivers of water hyacinth growth and sprawl: Temperature, ph. levels, Solar radiation

The best conditions for water hyacinth growth are daylight, temperatures between 25°C and 30°C, and somewhat neutral waters with pH levels between 6 and 8.(DWAF, 2007; Wilson et al., 2005). The water hyacinth requires photosynthetic day length (Solar radiation) for biomass production (Güereña et al., 2015). Thus the ideal growth period of water hyacinth is during the day, especially during the summer months, when the solar radiation is at its peak (DWAF, 2007).

Similarly, several authors DWAF (2007); Güereña et al. (2015); Harding (2004); Thamaga & Dube (2018); Villamagna, A.M. and Murphy (2010) have identified the following factors as the anthropogenic drivers of water hyacinth growth and sprawl: Wastewater treatment plant discharges into catchments, Washed surface pollution such as animal waste, litter, and sewer spillages into the lake, Poor up-keep of sanitation systems water hyacinth result in overflows and leaks during rainstorms, Agricultural runoff (fertilizers are washed into the lake during rainstorms), Informal washing in the lake.

The anthropogenic determinants of water hyacinth constitute high levels of nutrient concentrations in lakes, such as nitrogen (N) and phosphorus (P) (Güereña et al., 2015). These nutrients are continually deposited in lakes and enrich the water with dissolved nutrients. The dissolved nutrients are inevitably taken up by the water hyacinth, resulting in the rapid expansion of the weed across the lake (DWAF, 2007; Harding, 2004; Thamaga, K.H. and Dube, 2018).

2.1.5. Mapping Water Hyacinth by using Remote Sensing

Over the last 30 years, a variety of satellite-borne sensors have been utilized to collect data on water hyacinth and provide insight into biological activity occurring within water bodies (Cavalli et al., 2009). The increased use of remote sensing data in mapping invasive species is linked to the capacity of remote sensing data to offer a variety of new applications that can quickly and syn-optically monitor and manage large areas. For example, remote sensing has made it possible to examine aquatic weeds, environmental hazards, natural resources, and water quality monitoring in real time. Satellite data can be used to capture the spatial and temporal distribution of aquatic macrophytes in a timely and cost-effective manner (T. Dube et al., 2014; Erin Lee Hestir et al., 2015; Shekede et al., 2008). Furthermore, satellite sensors' continuous coverage provides spatial data for both short and long-term monitoring, which is critical for detecting and evaluating the control measures' strengths (Penatti et al., 2015). As a result, satellite imaging has been shown to be a trustworthy main data source, and it is now widely employed in ecological and environmental studies (Aplin, 2005).

a) Mapping invasive species using multispectral data

Multispectral sensors (MSS), Landsat, and Satellite Pour l'Observation de la Terre (SPOT) imagery have often been preferred for the monitoring of aquatic weed dispersal and often achieve high accuracies (Dube et al., 2017; Dube et al., 2014; Shekede et al., 2008). Landsat and SPOT data are readily available, have medium spatial resolutions, high temporal resolution, and are freely obtainable (Dube et al. 2017). These are characteristics that have driven the utilization of these sensors. However, the spectral resolutions, and spatial resolutions are at times limitations of MSS data use, as they are often not adequate (fine to coarse spatial extents and narrow spectral range) for effective vegetation mapping and identification (Adam et al., 2017).

Shekede et al. (2008) utilized the supervised classification technique to map the distribution of water hyacinth in Lake Chivero, Zimbabwe, using Landsat imagery. The authors were able to map the extent of areas in Lake Chivero covered by water hyacinth for the years 1976, 1989, and 2000.

Shekede et al., (2008) observed a decline in the distribution of water hyacinth in the classified images from 42%, to 36%, and finally 22% for the 1976, 1989, and 2000 images, respectively. A more recent study, Dube et al. (2017) tested the detection and discriminatory potential of Landsat-8 OLI in mapping water hyacinth. The authors were able to map water hyacinth at high accuracies ranging between 84 % and 100%. Likewise, Ongore et al. (2018) utilized Landsat 7 ETM, Landsat-8 OLI, and Sentinel-2 MSI imagery to map and assess the distribution of the invasive water hyacinth in the Kenyan portions of Lake Victoria, utilizing both supervised and unsupervised classification techniques. The integration of the imagery from various sensors enabled the authors to detect the fluctuations in the spatiotemporal distribution of water hyacinth for five years (Ongore et al., 2018).

b) Mapping invasive species using hyperspectral data

Several authors have proved hyperspectral data to have very high accuracies in classifying aquatic weeds (Asner et al., 2008; Hansen et al., 2006). Hyperspectral data have high spatial resolutions, <1 m – 5 m, and high spectral resolutions, spectral bands range from hundreds to thousands and go beyond the infrared region of the spectrum (Foody, 2002). Nevertheless, the costly acquisition, availability, high dimensionality of the acquired information, tedious pre-processing, and the requirement for specialized equipment and programs, have limited the use of hyperspectral data (Asner et al., 2008).

Mapped water hyacinth in the California Delta using decision tree classification and airborne hyperspectral imagery (Erin Lee Hestir et al., 2015). The HyMap data had a spatial resolution of 3 m and covered a regional area of 2139 km_2. The classification from the binary trees yielded a producer’s accuracy of 61.9 % and a user’s accuracy of 51.4 %. Further classification of the hyacinth based on phenology, yielded producers accuracies of 86.5% and 44.9% for healthy water hyacinth and flowering water hyacinth respectively (Erin Lee Hestir et al., 2015). These are conflicting results; the low accuracies can be attributed to the presence of mixed pixels (Thamaga, K.H. and Dube, 2018). Underwood et al. (2006) used spectral mixture analysis to classify hyperspectral map imagery to map water hyacinth and Brazilian waterweed in the Sacramento-San Joaquin Delta, USA. The resultant overall accuracies of water hyacinth mapped from five sites within the Delta and the entire Delta were 73% and 65% respectively.

c) Mapping invasive species using new generation multispectral data

According to Adam et al., (2017), the last decade has seen the emergence of new generation imagery characterized by high spatial and spectral resolutions. Landsat-8 OLI, Rapid Eye, Sentinel-2, and WorldView-2 are examples of new-generation sensors, with spatial resolutions of 30 m, 5 m, 10-60 m, and 1.5-2 m, respectively (Adam et al., 2017). These resolutions ensure crisper images with more details on land cover mapping.

John & Nath (2014) Fine spatial resolution WorldView-2 imagery combined with various band combinations, based on spectral properties of vegetation reflectance obtained from fieldwork, performed unsupervised classification of aquatic weeds. This method resulted in the perfect classification of the weeds, 100%, with a band combination of red-edge, green, coastal blue, and red-edge. The subsequent classification with the band combination of NIR-1, green, coastal blue, and NIR-1 obtained a considerably good average of 82.35 %.

Timothy Dube et al., (2017) also conducted two studies utilizing the new generation sensor Landsat-8 OLI. The first study was conducted in Lake Manyame and the second was undertaken in Lake Chivero both situated in Zimbabwe. In the Lake Manyame study, the authors used Discriminant Analysis (DA) and Partial Least Squares Discriminant Analysis (PLS-DA) in classifying the Landsat-8 OLI image. The classification yielded an overall accuracy of 95% for water hyacinth mapped during the dry season and 91 % for hyacinth mapped during the wet season. The second study, conducted in Lake Chivero, utilized a Discriminant Analysis (DA) to analyze the image. The variance test resulted in an overall classification of 92 % of the water hyacinth.

2.1.6. Change detection

Change detection Analyses are also used on multi-temporal datasets to describe the size, nature, rate of change in land cover, and spatial trend across space and time. (Singh, 1986) defined change detection as the process of identifying changes in the state of an object or phenomenon by viewing images at various times. Many statistical and mathematical algorithms are available for estimating changes using Remote Sensing Data (Singh, 1986). Algorithms for change detection include but are not limited to vegetation index rationing, principal component analysis (PCA), image differencing, and post-classification comparison(Singh, 1986). The change detection Statics in ENVI 5.4 uses the post-classification comparison algorithm to estimate the change in a region(Hegazy, I.R and Kaloop, 2017). Thus the change detection statics will be utilized in this study. The change detection statics require the input of different time images, an initial stage, and a final stage image. Those images are utilized to compute the change statics based on a class for class comparison of the LULCC which will be classified in the study area. The post-classification comparison identifies classes where pixels in the final state image have changed from the initial image. The change detection statistics will be produced between the images for the 2016 GC, 2018 GC, and 2020 GC.

i. Image regression

In the image regression method of change detection, pixels from time t1 are assumed to be a linear function of the time t2 pixels (Singh, 1986). Under this assumption, it is possible to estimate an image obtained from t2 by using least-squares regression. According to Abuelgasim et al., (1999) the image regression technique consider the differences in the mean and variance between pixel values for different dates. This consideration minimizes the influence of differences in atmospheric conditions.

ii. Post classification

This method is the most simple and obvious change detection based on comparing independently classified images (Singh, 1986). The researcher’s maps of changes can be produced, which shows a complete matrix of changes from times t1 to time t2. Based on this matrix, if the corresponding pixels have the same category label, the pixel has not been changed, or else the pixel has been changed (Singh, 1986).

iii. Image Ratio Method

In the image ratio method, images must be registered beforehand and rationed band by band. The results of the image ratio are interpreted with a threshold of values. If the ratio of the two images is 1, it means that there is no change in the land cover classes whereas a ratio value of greater or less than 1 indicates a change in land cover classes (Singh, 1989; Bekalo, 2009).

iv. Image Differencing Method

Image difference is one of the most extensively applied change detection methods. It can be applied to a wide variety of images and geographical environments. In this technique, images of the same area, obtained from times t1 and t2, are subtracted pixel-wise. It is generally conducted based on a grayscale which used to show the spatial extent of changes in the two images. A threshold value is required for the gray of the difference image to examine the changed and unchanged regions (Singh, 1989).

2.2. Related Studies

2.2.1. Water hyacinth of Lake Abaya

Various research on the weeds increased spread and recommendations for monitoring methods have been conducted. According to Mengist & Moges (2019), Water hyacinths' widespread distribution and abundance have resulted in diminished water availability and water biodiversity in Abaya Lake.

On the other hand, Mengistu et al. (2017) In Lake Abaya, southwestern Ethiopia, researchers studied the influence of water hyacinth on macrophyte species composition and biodiversity. By comparing four sites in Lake Abaya, two of which were infested with hyacinths and two of which were not, each with 15 plots. Their findings revealed that water hyacinth had a negative impact on macrophyte community composition, abundance, and diversity.

Despite the severity of the expansion, its spatiotemporal distribution, the extent, and trend of expansion of the weed are not well known. The water hyacinth's spatial extent and rate of expansion must be investigated.

2.2.2. Mapping Water Hyacinth by using satellite imagery

Some of the case studies reviewed for spatiotemporal analysis of water hyacinth are summarized in Table 2.1.

Authors	Title	Data Used	Model Used	Aim of the study and conclusion
Youssra et al., (2019)	Multi-temporal RS based on an FVC reflectance period using sentinel monitoring Eichhornia crassipes (water hyacinth) on a Mediterranean River.	-Sentinel-2 image	-Fractional vegetation cover (FVC)	-To monitor water hyacinth development and estimate the total area it colonizes in the river corridor. -Result showed that it assessed the potential of sentinel-2 images to quantify vegetation area. -Water hyacinth cover and dynamics were mapped successfully involving this method.
Tewachew et al., (2019)	Detecting Spatiotemporal expansion of water hyacinth (Eichhornia crassipes) in Lake Tana, Northern Ethiopia.	-Landsat 8	-Decision Tree -Maximum Likelihood classification technique	-To detect the Spatiotemporal trend of the weed during 2013, 2015, and 2017. -The result showed that water hyacinth coverage has shown significant expansion for the years between 2013 and 2017 with 5-year intervals the amount of coverage increased from 112 ha and 168 ha And then to 1512 ha. -Specifically, the result shows that its coverage and expansion are increasing very fast towards the lakes as compared to other coverage types, which is dangerous for the sustainability of the lake.
Timothy et al., (2017)	Testing the detection and discrimination potential of the new Landsat 8 satellite data on the challenging water hyacinth(Eichhornia crassipes) in the fresh water ecosystem	-by using visible, near-infrared, and thermal band information derived from the land sat 8	-Discriminant Analysis (DA) -Partial Least Square Discriminant Analysis(PLS-DA)	-Detecting and monitoring the spatial distribution, configuration and propagation rate of aquatic water weeds (i.e. water hyacinth) in a freshwater ecosystem.

		multispectral sensors.		-Result showed that the spatial distribution and configuration of water hyacinth could be accurately detected and mapped with an overall classification accuracy of 95% using Landsat 8. -The result showed that the different growing stages could be spectrally detected and mapped. - This study has demonstrated that the Landsat 8 bands 5, 6, 7, 8, 10 & 11 are the most influential in detecting and mapping water hyacinth.

Table 2.1: Summary of some of the case studies reviewed

CHAPTER III: MATERIALS AND METHODS

3.1. Description of the Study area

3.1.1. Location of the study area

Lake Abaya is one of the two southernmost Rift Valley lakes in Ethiopia. It is the second-largest lake in the country next to Lake Tana, a lake that has recently been overrun by water hyacinth, similar to Lake Abaya. Abaya is located between 5˚55'9"N to 6˚35'30"N latitude and 37˚36'90"E to 38˚03'45"E longitude (Figure 3.1) The Lake, including its islands, has a total area of 1108.9 km2. It has a maximum length of 79.2 km and a maximum width of 27.1 km. It is located at an average altitude of 1177.442 meters above sea level (Google Earth, n.d.).

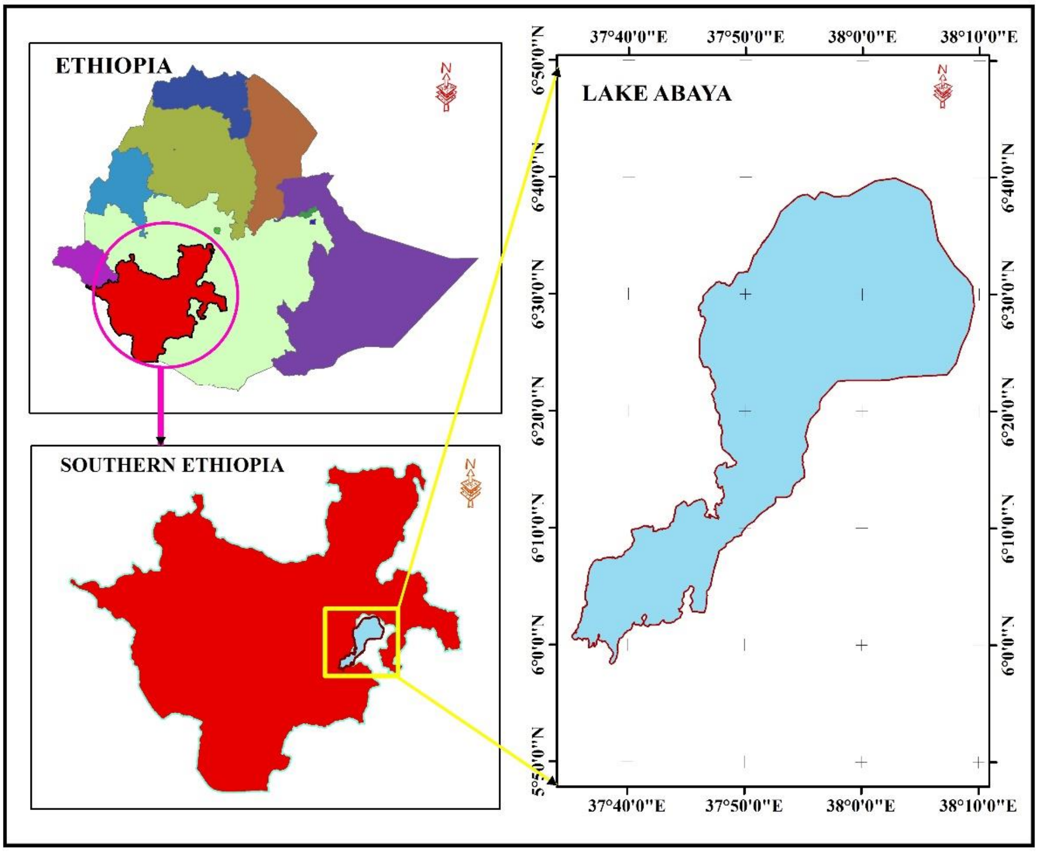


Figure 3.1: Location map of Study Area

3.1.2. Climate

Based on ten years of climatic data, (2001-2010), the Lake Abaya basin exhibits a bimodal rainfall trend. It has an average annual temperature of 22.9˚C and an average rainfall of 768 mm. The study areas rainy season ranges from March to November, with the lowest monthly rainfall in January and the highest in May. From December to February, the hot and dry season is in full swing. The mean minimum daily temperature of the coldest month and the mean maximum temperature of the warmest months are 15.0˚C and 32˚C, respectively.

3.2. Research design

The conceptual structure or the design of the research project that the researcher followed in conducting the research is essential to clearly define and visualize the whole image of the work. Defining the research design highly contributes towards result findings by showing overall highlights of methods. Therefore, before the commencement of the research techniques, it is imperative to prepare tracks of the research by assembling all the requirements for the problem-solving objective (see Figure 3.2).

3.2.1. Approaches to the Research

In this study, both Quantitative and Qualitative research approaches are implemented to get the final result and it can be known as Mixed Approach. Even though the qualitative side has more weightage than the quantitative, it is difficult to attain the objective of the study without the involvement of both.

3.2.2. Research type

It is known that there are different types of researches to be employed based on the goal (purpose), Type of data, Field of study, or the aim (objective) of the research. Therefore, this study is categorized under the applied research type. Because the result can be applied to solve real-world problems.

3.3. Data Sources and Types

All the data were used to achieve the objectives of this study. These data and their sources are explained in (Table 3.1 and Table 3.2) below.

Table 3.1: List of remote sensing data

Satellite	Spatial resolution	source	Acquisition time
Sentinel-2	10 meter	USGS (GLOVIS) Earth Explorer	December 2016
Sentinel-2	10 meter	USGS (GLOVIS) Earth Explorer	December 2018
Sentinel-2	10 meter	USGS (GLOVIS) Earth Explorer	December 2020

Table 3.2: List of other data

Data name	Data form	Use	Source
GPS(handheld) & Google map	Point collection	Accuracy assessment	Field(Collecting from the field)
Topographic map of 1979	Map (1:50,000)	Geo-referencing	Ethiopia Geospatial Information Institute

3.4. Software's and Materials

The software that was used in this study was selected based on the capability to work on the existing problems in achieving the predetermined objectives. The details of the software for this study are tabulated and explained in (Table 3.3) below.

Table 3.3: List of software's and uses

No	Name	Version	Purpose
1	Computer with 8GB RAM	2018	Processing raw data and report writing
2	ArcGIS	10.8	To create land use the land cover map To land use land cover change detection For spatiotemporal analysis of water hyacinth
3	ERDAS Imagine 2015	15.00	Image preparation and processing
4	Google earth pro	2020	Taking coordinates and assessment of geographical locations
5	Mendeley Desktop	1.19.6	To insert citations and references used for the study.
6	Microsoft word, Excel	2018	Integrating attribute data and compositing final thesis

3.5. Conceptual framework

The theoretical framework offered in the literature review on several ideas connected to mapping and identifying spatiotemporal distribution and rate of expansion of water hyacinth from satellite data.

Aside from the theoretical framework, many investigations in the area were conducted regarding the weed's increasing expansion and recommendations for monitoring methods. According to Mengist & Moges (2019), Water hyacinths' widespread distribution and abundance have resulted in diminished water availability and water biodiversity in Abaya Lake. On the other hand, Mengistu et al., (2017) In Lake Abaya, southwestern Ethiopia, researchers studied the influence of water hyacinth on macrophyte species composition and biodiversity. By comparing four sites in Lake Abaya, two of which were infested with hyacinths and two of which were not, each with 15 plots. Their findings revealed that water hyacinth had a negative impact on macrophyte community composition, abundance, and diversity. Despite the severity of the spread, its spatiotemporal distribution, the extent, and trend of expansion of the weed are not well known. The water hyacinth's spatial extent and rate of expansion need to be investigated. The conceptual framework for achieving the study's aims and answering the research questions is depicted graphically below. As a result, the following systematic actions in the flowchart indicated in Figure 3.2 were conducted and completed.

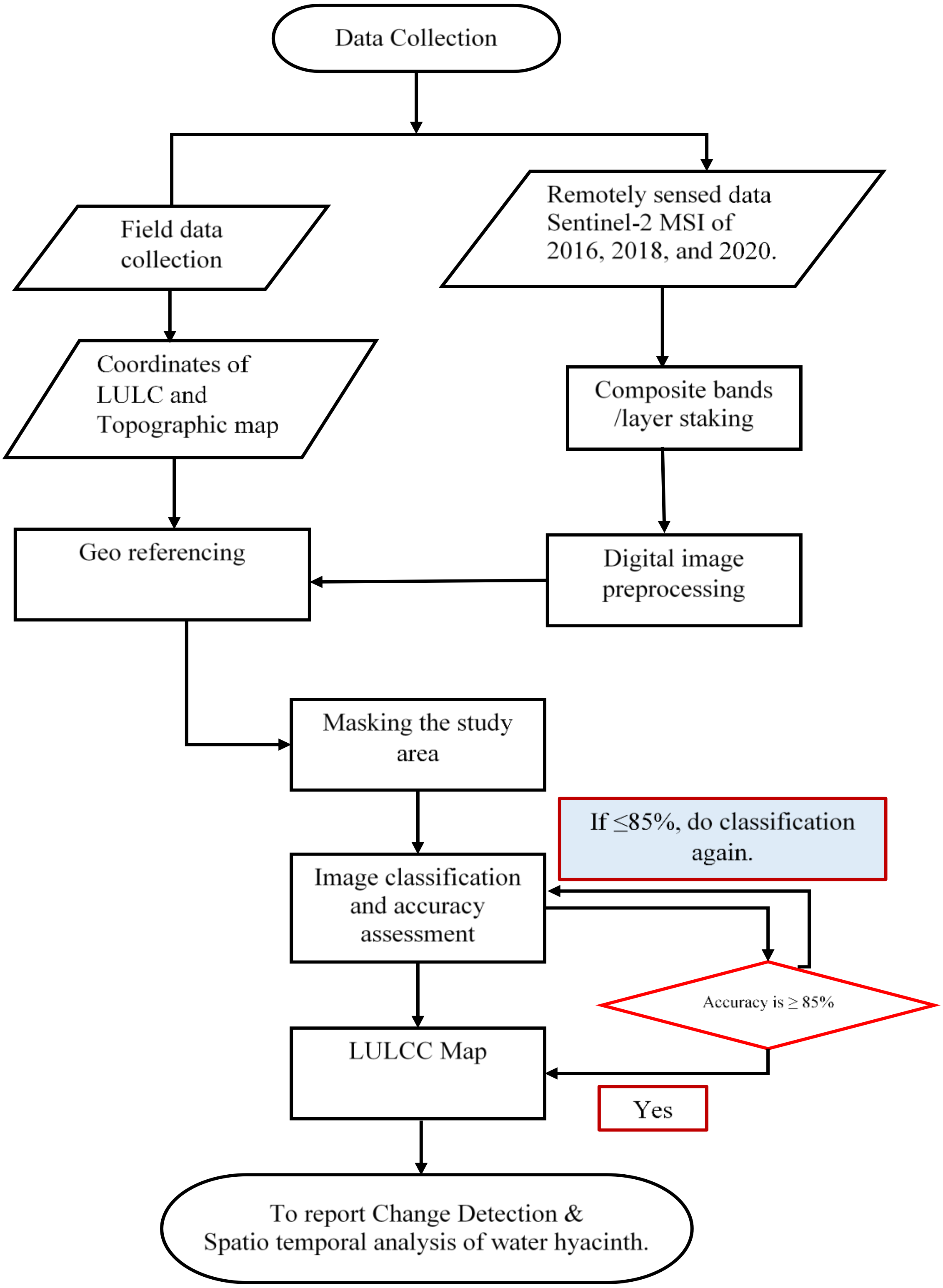


Figure 3.2: Conceptual framework of the thesis work.

3.6. Methods of Data Analysis

3.6.1. Remote sensing data acquisition

Sentinel-2 MSI satellite sensors were used to collect remotely sensed imagery to map the current spread of water hyacinth in Abaya Lake. Because of its high spatial resolution, Sentinel-2 images were utilized to map and distinguish water hyacinth from other land use land cover classes (LULC) in the research area. Sentinel-2 MSI images covering the study area are available for free download from the USGS Earth Explorer portal, http://earthexplorerusgs.gov/, and the European Space Agency's Copernicus Open Access Hub, http://scihub.copernicus.eu, respectively.

Sentinel-2 MSI is a multi-spectral imaging mission. Sentinel-2 MSI is a high spatial resolution sensor, commissioned by ESA Copernicus with a 290 km^2 swath width. The mission consists of twin satellites that provide systematic coverage, with a 5-day revisit frequency, as a pair, and 10 days individually. The high revisit period makes Sentinel-2 imagery applicable to mapping water hyacinth distribution. Water hyacinth distribution is continually changing. Thus periods in between mapping water hyacinth distribution should be minimal to show its distribution over time accurately. The movement of water hyacinth is affected by the directions and speed of water and wind flows. Thirteen spectral bands ranging between the spectral regions of 430 nm and 2323 nm are employed to measure reflected solar radiances by the Sentinel-2 MSI (Drusch et al., 2012). Four of the thirteen spectral bands have a fine spatial resolution of ten meters, six have a mild spatial resolution of twenty meters, and the remaining three have a coarse resolution of sixty meters (Table 3.3).

Table 3.4: Spectral, spatial and radiometric resolutions Sentinel-2 MSI.

Sensor	Sentinel-2	
	Pixel size	Wavelength range
Band	(m)	(nm)
1	60	430-457
2	10	448-546
3	10	538-583
4	10	646-684
5	20	694-713
6	20	731-749
7	20	769-797
8	10	763-908
8A	20	848-881
9	60	932-958
10	60	1336-1411
11	20	1542-1685
12	20	2081-2323
Swat Width		290 km
Orbit Altitude		786 km
Revisit Time	10 days (S2A)/5 days (S2A/B)	

3.6.2. Ground Reference Data

Bare land, water bodies (Lake Abaya), shrubs, water hyacinth, and papyrus were the principal land covers evaluated in this study's area. Except for water bodies, water hyacinth, and papyrus, a handheld global positioning system was employed to measure sampling sites for each land cover to be used in classifying the satellite image at each land cover site. The field survey took place during the dry season, which coincided with the acquisition of satellite images. The GPS, Google earth and Google map measured sample points from each land cover type were then imported into ArcGIS 10.8 and saved as point maps. The preprocessed sentinel-2 MSI images were then overlaid with the point maps to obtain the reflectance of each land cover category at each point.

Land use and land cover classes present in the study were defined using the Sentinel-2 MSI. Ground reference samples, of no less than 30, were gathered for each of the LULCC by randomly creating ground reference points across the various LULCC images. Obtaining ground reference points from images is a meticulous process. The ground reference points have to be within a single pixel which is pure. This is to ensure that there is no confusion in the spectral properties of the different LULC. Many samples were required for each LULC on each of the images to ensure high classification accuracy (Mesev, 2010). Samples are acquired for the retrieval of the unique spectral signature characteristics of the different LULC classes. The training dataset used to classify the image and test dataset to validate the classification accuracy.

3.6.3. Image Classification

Classification is the process of sorting pixels into a finite number of individual classes, or categories of data, based on their data file values. If a pixel satisfies a certain set of criteria, then the pixel is assigned to the class that corresponds to those criteria. For the first part of the classification process, the computer system must be trained to recognize patterns in the data. Training is the process of defining the criteria by which these patterns are recognized. The result of training is a set of signatures, which are the criteria for a set of proposed classes.

Image classification is the process of grouping pixels based on their digital numbers (DNS) into spectral and/or informational classes that capture some features that are interesting in mapping.

Supervised classification: In supervised classification, the image analyst "supervises" the selection of spectral classes that represent patterns or land cover features that the analyst can recognize. The image processing software is guided by the user to specify the land cover classes of interest. The samples of these land cover classes are called "training sites". The image classification software will be used in the training sites to depict the appropriate classes in the entire image. The classification of land cover is based exactly on the spectral signatures that are defined in the training set based on the knowledge of the user by examining the signatures that best accentuate the differences in land cover.

Training is the process of defining criteria for recognizing spectral patterns, creating informative classes for each spectral class, and categorizing each pixel in an image data set into the spectral class that most closely resembles based on a mathematical decision rule (Maxwell, 1976).

It is absolutely important when the training area is a homogenous sample of the respective class, so that the comparison between spectral and LULC will be easier (aria 1993). Two or more training areas per class were considered to accommodate within class variability. The process of training would end up creating information classes i.e. LULC types (Lillesand and Kiefer, 2014; Eastman 1995). A statistical characterization of each information class would then be developed using ERDAS IMAGINE software (2015 version) to develop a signature file known as "signature analysis". Once a statistical characterization has been achieved for each information class, the image is then classified by examining the reflectance of each pixel and making a decision about which of the signatures it resembles most (Eastman 1995).

The "maximum likelihood" classification algorithm is one of the most widely used classification techniques in remote sensing. The maximum likelihood classifier is a conventional statistical classification technique that allocates each pixel to the class with the highest likelihood (Mather & Koch 2011). Hence, these classification techniques were used to map the LULC of the study area.

Classification process and analysis of the different LULC classes were done using sentinel-2 MSI imagery acquired on 30 December 2016, 25 December 2018 and 24 December 2020. The sentinel-2 MSI images were downloaded from United States Geological (USGS) Earth Explorer (https://earthexplorer.usgs.gov/). The selection of sentinel-2 MSI images dates was influenced by the quality of the image especially for those with limited or low cloud cover. Each sentinel-2 MSI images was georeferenced to the WGS_84 and Universal Transverse Mercator Zone 37 north coordinate system.

To Ortho-rectify the satellite pictures, stacking was performed. After that, the image was processed using the ERDAS IMAGINE 2015 software. Each band's satellite picture was stacked in ERDAS Hexagon using the layer stacked function in the interpreter's main icon utility. The study area image was then obtained from the stacked satellite image by clipping the study area using ArcGIS 10.8 software.

According to Maxwell (1976) "the user develops the spectral signatures of known categories, such as urban and forest, and then the software assigns each pixel in the image to the cover type to which its signature is most comparable," and "the software assigns each pixel in the image to the cover type to which its signature is most comparable." "The most commonly utilized method for quantitative analysis of remote sensing image data is supervised classification" (Drusch et al., 2012). After defining an area of interest (AOI), or training classes, the supervised classification was used. To represent a certain class, more than one training area was used. The training locations were chosen using Sentinel-2 MSI Image, Google Earth, and Google Maps.

On supervised classification, the basic sequence operation was as follows:

i. Defining Training Sites

The first stage in supervised classification is to identify the areas that will serve as training sites for each land cover class. This is usually accomplished through the use of digitized on-screen features. Areas of Interest are the created features (AOI). The training sites were chosen based on areas that were clearly recognizable in all image sources.

ii. Extracting Signatures

After digitizing the training site (AOI), the next step was to develop statistical characterizations of the information. In ArcGIS 10.8, these are known as Signature editors. The purpose of this phase was to build a signal (SIG) file for each of the informational classes. The SIG files include a variety of information regarding the various land cover classes. The SIG file is stored as a dialog when the complete signature has been produced. To represent a certain class, one or more training areas were used. The whole Signature editor was chosen to be employed on the classification process during the supervised classification procedure. The classify/supervised option was then selected from the Editor Menu bar, classify/supervised. The image was classified into five classes namely; water body, water hyacinth, papyrus, bare land, and shrubs (Table 3.5).

Table 3.5: Land Cover Classification Scheme.

Land Cover	Description
Water body	Lakes, reservoirs, streams, rivers, swamps.
Water hyacinth	The water hyacinth is a free-floating perennial aquatic plant (or hydrophyte) native to tropical and sub-tropical South America. With broad, thick, glossy, ovate leaves, water hyacinth may rise above the surface of the water as much as 1 meter (3 feet) in height.
Papyrus	A leafless aquatic plant can reach a height of 4 to 5 meters (13 to 16 feet). When the plant is young, it creates a grass-like clump of triangular green stems that come up from thick, woody rhizomes. Each stem is capped by a dense cluster of thin, bright green, thread-like rays that measure 10 to 30 cm (4 to 10 in) in length and resemble a feather duster.
Bare land	Lands with exposed soil, sand, or rocks that are never more than 10% vegetated at any time of the year. Strip mines, quarries, and gravel pits are examples of bare land and exposed rocks.
Shrubs	Lands with less than 2 meter height woody vegetation. The foliage of the shrub can be either evergreen or deciduous.

3.6.4. Accuracy Assessment

Overall accuracy is the ratio, represented as a percentage, between the total number of the validation data samples and the number of accurately classified test data samples, while producer's accuracy represents the number of accurately classified test samples per LULCC. User's accuracy expresses the possibility that of test data samples belonging to a specific LULCC as well as the performance of the classifier in accurately assigning a test sample to such a class.

Accuracy assessment is an important part of any classification project. It compares the classified image to another data source that is considered to be accurate or ground truth data.

Ground truth can be collected in the field; however this is time consuming and expertise. Ground truth data can also be derived from interpreting high resolution imagery, existing classified imagery, or GIS data layers.

The most common way to assess the accuracy of a classified map is to create a set of random points from the ground truth data and compare that to the classified data in a confusion matrix. Although this is a two-step process, you may need to compare the result of different classification methods of training sites, or you may not have ground truth data and are relaying on the same imagery that you used to create the classification.

Accuracy Assessment Formula

$$\text{Users Accuracy} = \frac{\text{Number of Correctly Classified Pixels in each Category}}{\text{Total number of Classified Pixels in that Category (The Row Total)}} \times 100$$

……Equation 1.

$$\text{Producer Accuracy} = \frac{\text{Number of Correctly Classified Pixels in each Category}}{\text{Total Number of Reference Pixels in that Category (The Column Total)}} \times 100$$

……Equation 2.

$$\text{Overall Accuracy} = \frac{\text{Total Number of Correctly Classified Pixels (Diagonal)}}{\text{Total Number of Reference Pixels}} \times 100 \ldots\ldots\ldots \textit{ Equation 3.}$$

$$Kappa\ Coefficient\ (T) = \frac{(TS \times TCS) - \sum(Column\ Total \times Row\ Total)}{TS^2 - \sum(Column\ Total * Row\ Total)} \times 100$$

……Equation 4.

Where:

TS= Total sample

TCS= Total corrected Sample

3.6.5. Change detection

Change detection Analyses are also used on multi-temporal datasets to describe the size, nature, rate of change in land cover, and spatial trend across space and time. (Singh, 1986) defined change detection as the process of identifying changes in the state of an object or phenomenon by viewing images at various times. Many statistical and mathematical algorithms are available for estimating changes using Remote Sensing Data (Singh, 1986). Algorithms for change detection include but are not limited to vegetation index rationing, principal component analysis (PCA), image differencing, and post-classification compare

(Singh, 1986).Thus the change detection statics will be utilized in this study. The change detection statics require the input of different time images, an initial stage, and a final stage image. Those images are utilized to compute the change statics based on a class for class comparison of the LULCC which will be classified in the study area. The post-classification comparison identifies classes where pixels in the final state image have changed from the initial image. The change detection statistics were produced between the images for the 2016 GC, 2018 GC, and 2020 GC.

CHAPTER IV: RESULT AND DISCUSSION

4.1.Coverage of the lake water body and land use in 2016.

90 % overall accuracy and an 87.82 % kappa coefficient were attained in the land cover classification of 2016. The results of the classification reveal that the proposed approach appropriately classifies each class. Water hyacinth had a low coverage compared to other classes in 2016, accounting for 2303.49 hectares (1 %) of the entire study area, i.e. 164095.8326 ha as indicated in Table 4.1 and 5038.68 ha (3%) of the study area is covered with papyrus. Whereas most of the area 113790.78 ha (69 %), was covered with water bodies, the peripheries of the lake were covered with water hyacinth and papyrus.

Table 4.1: Study area coverage in 2016.

No.	Name of the class	Area (ha.)	Percent (%)
1	Bare Land	38114.27049	23%
2	Papyrus	5038.681142	3%
3	Shrubs	4850.041799	3%
4	Water Body	113790.7839	69%
5	Water Hyacinth	2303.49555	1%
	Grand Total	**164097.83**	100%

The other command areas for the water hyacinth around the periphery of the study site were bare land, and shrubs. The study site's water hyacinth coverage in 2016 was concentrated on the northeastern periphery. As illustrated in Figure 4.1, the rest of the marginal land was mostly covered in barren ground, shrubs, and papyrus.

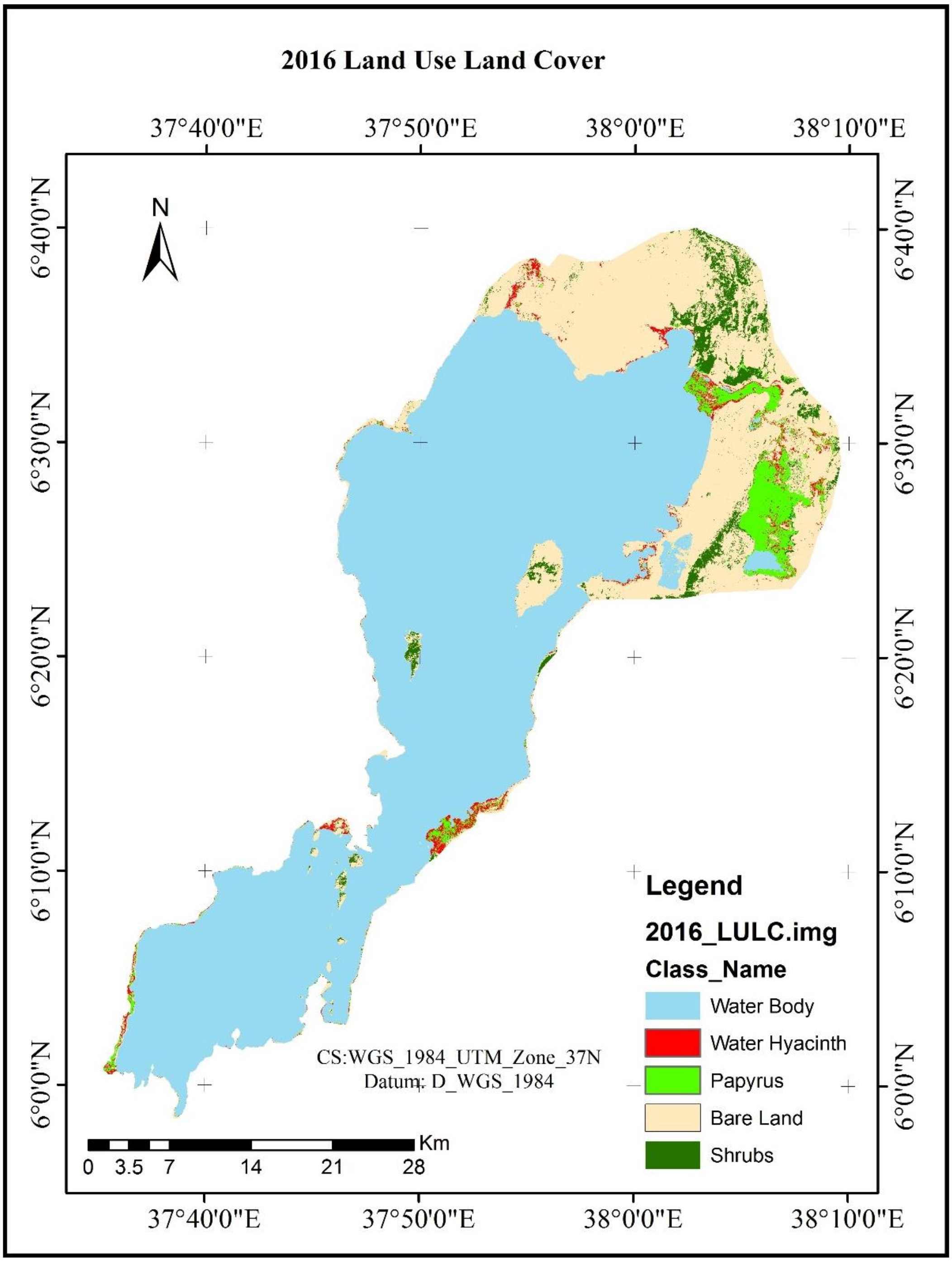


Figure 4.1: Land use Land Cover Map of the year 2016.

4.1.1. Accuracy Assessment for the classification of 2016.

Table 4.2: Confusion matrixes for the classification 2016.

	Water Body	Water Hyacinth	Papyrus	Bare Land	Shrubs	**Total User**
Water Body	**31**	0	0	0	0	31
Water Hyacinth	1	**26**	2	1	0	30
Papyrus	1	2	**27**	0	0	30
Bare Land	0	1	1	**28**	2	32
Shrubs	0	1	1	2	**27**	31
Total Producer	33	30	31	31	29	**154**

User accuracy

Water Body = 31/31*100=100

Water Hyacinth = 26/30*100=86

Papyrus = 27/30*100=90

Bare Land = 28/32*100=87.5

Shrubs = 27/31*100=87

Producer accuracy

Water Body = 31/33*100=93.93

Water Hyacinth = 26/30*100=86.66

Papyrus = 27/31*100=87

Bare Land = 28/31*100= 90

Shrubs = 27/29*100=93

TS=154

TCS=139

Over All Accuracy = (31 + 26 + 27 + 28 + 27) / 154 * 100 = <u>**90 %**</u>

Kappa Coefficient (T) = ((154*139) – 4744) / (154^2 - 4744)

= (16662/18972) * 100 = **87.82%**

4.2. Coverage of the lake water body and land use in 2018.

91.55 % overall accuracy and an 89.44 % kappa coefficient were attained in the land cover classification of 2018. Water hyacinth coverage was predicted to be 5327.26 hectares in 2018, covering for 3% of the study area. Its coverage has expanded by 3023.77 hectares during 2016.According to this statistics, the water hyacinth coverage area in 2018 is more than double the area covered in 2016, according to the previous data. This is a significant increase in a short period of time. This suggests that an increase in water hyacinth coverage takes control of the water surface in a short period of time. At 2018, the water body coverage in the study area was 111858.87 ha, whereas in 2016 it was 113790.78 ha (see Table 4.3).

Table 4.3: Study area coverage in 2018.

No.	Name of the class	Area (ha.)	Percent (%)
1	Bare Land	38627.33073	24%
2	Papyrus	4106.007	3%
3	Shrubs	4178.105482	3%
4	Water Body	111858.8779	68%
5	Water Hyacinth	5327.268487	3%
	Grand Total	**164097.5896**	100%

As a result, water hyacinth and papyrus have taken over the water body, and in 2018 rapid expansion of the water hyacinth was seen in the northeastern part of the lake, as shown in Figure 4.2.

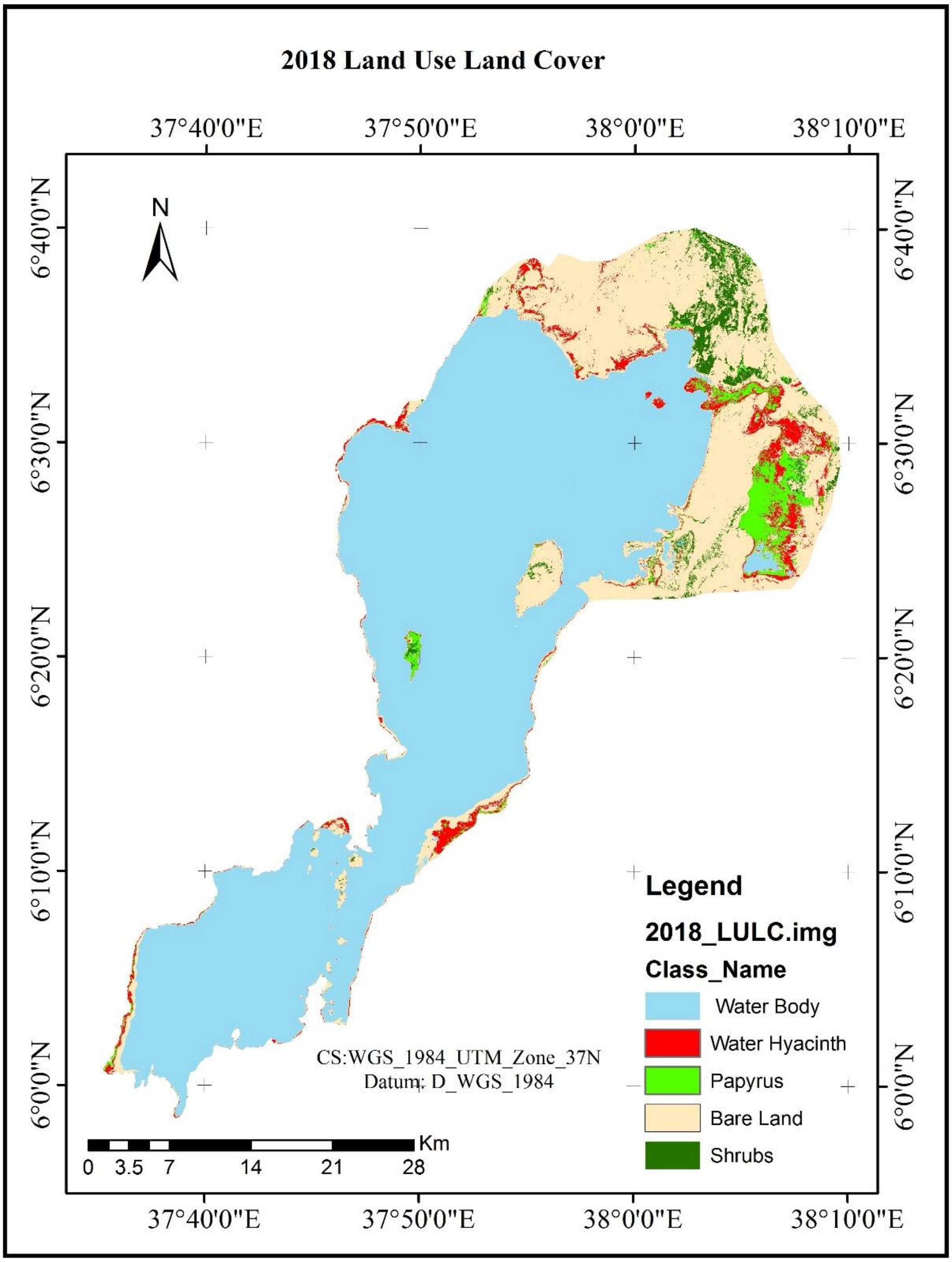


Figure 4.2: Land use Land Cover Map of the year 2018.

4.2.1. Accuracy Assessment for the classification of 2018.

Table 4.4: Confusion matrixes for the classification 2018.

	Water Body	Water Hyacinth	Papyrus	Bare Land	Shrubs	**Total User**
Water Body	**29**	1	0	0	0	30
Water Hyacinth	3	**28**	0	1	0	32
Papyrus	0	1	**27**	1	1	30
Bare Land	0	0	1	**28**	2	31
Shrubs	1	0	0	1	**29**	31
Total Producer	33	30	28	31	32	**154**

User accuracy

Water Body = 29/30*100=96.66

Water Hyacinth = 28/32*100=87.5

Papyrus = 27/30*100=90

Bare Land = 28/31*100=90

Shrubs = 29/31*100=93

Producer accuracy

Water Body = 29/33*100=87.87

Water Hyacinth = 28/30*100=93

Papyrus = 27/28*100=96

Bare Land = 28/31*100=90

Shrubs = 29/32*100=90

TS= 154

TCS= 141

Over All Accuracy = (29+28+27+28+29)/154*100= **<u>91.55 %</u>**

Kappa Coefficient (T) = ((154*141) – 4743) / (154^2 – 4743)*100

= (16971/18973) * 100 = **<u>89.44%</u>**

4.3. Coverage of the lake water body and land use in 2020

87 % overall accuracy and an 86 % kappa coefficient were attained in the land cover classification of 2020. In 2020, water hyacinth covered 5942.61 ha (4 percent of the overall study area), as shown in Table 4.5. The water hyacinth in 2018 was 5327.27 ha, and the result of 2020 showed that the expansion of water hyacinth is significantly increased.

Table 4.5: Study area coverage in 2020.

No.	Name of the class	Area (ha.)	Percent (%)
1	Bare Land	33751.04042	21%
2	Papyrus	3336.198646	2%
3	Shrubs	3058.0049	2%
4	Water Body	118010.1081	72%
5	Water Hyacinth	5942.617344	4%
	Grand Total	**164097.9694**	100%

Water hyacinth expansion was found in practically every region of the study area, but it was particularly noticeable in the northeastern part of the study area (see figure 4.3).

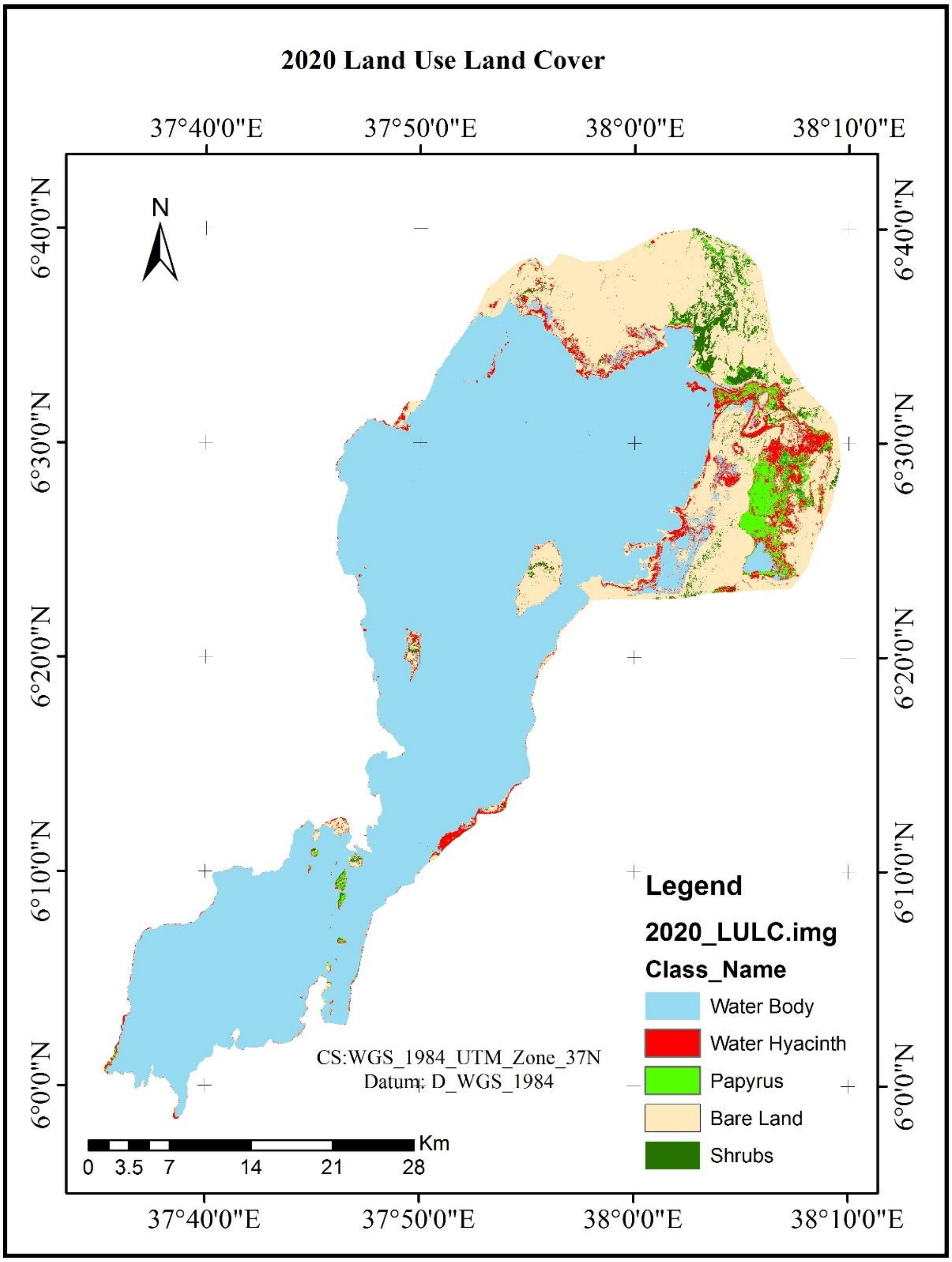


Figure 4.3: Land use Land Cover Map of the year 2020.

4.3.1. Accuracy Assessment for the classification of 2020.

Table 4.6: confusion matrix for the classification of 2020.

	Water Body	Water Hyacinth	Papyrus	Bare Land	Shrubs	**Total User**
Water Body	**30**	1	0	0	0	31
Water Hyacinth	1	**29**	1	3	1	35
Papyrus	0	4	**23**	0	3	30
Bare Land	1	1	0	**30**	2	34
Shrubs	0	0	1	2	**26**	29
Total Producer	32	35	25	35	32	**159**

User accuracy

Water Body = 30/31 * 100 = 96

Water Hyacinth = 29/35 * 100 = 82

Papyrus = 23/30 * 100 = 77

Bare Land = 30/34 *100 = 88

Shrubs = 26/29 * 100 = 90

Producer accuracy

Water Body = 30/32 *100 = 93

Water Hyacinth = 29/35 *100 = 83

Papyrus = 23/25 *100 = 92

Bare Land = 30/35 *100 = 86

Shrubs = 26/32* 100 =81

Over All Accuracy = (30 + 29 + 23 + 29 + 26) / 159* 100 = **87 %**

Kappa Coefficient (T) = ((21942-5085) / (24649 - 5085))*100 = **86 %**

4.4.Change detection analysis

As we can see the output of land use land cover change over the study area of the years selected report from the table five land category result is different in a given different sample years. According to the output in the first year i.e. 2016 the area coverage of water hyacinth is very low which is 2303 ha (1%) and lake body is covered large area, secondly (2018) the area covered by water hyacinth is more than double i.e. 5327.26 (3% of the study area) from the previous and the area of lake body is somehow decreased by 1931.90 ha. Finally the area covered by water hyacinth in 2020 is significantly increasing and a dramatic change is happening. The total amount of land use land cover classification for each category area in hectares and percentage from the year 2016-2020 shown in the following (see Table 4.7).

Table 4.7: land use land cover classification of the year 2016, 2018 and 2020.

LULC	2016		2018		2020	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Bare Land	38114.27	23 %	38627.33	24 %	33751.04	21 %
Papyrus	5038.68	3 %	4106.00	3 %	3336.19	2 %
Shrubs	4850.041	3 %	4178.10	3 %	3058.00	2 %
Water Body	113790.78	69 %	111858.87	68 %	118010.10	72 %
Water Hyacinth	2303.49	1 %	5327.26	3 %	5942.62	4 %
Total	**164097.83**	**100 %**	**164097.58**	**100 %**	**164097.97**	**100 %**

The land use and land cover change detection based on remote sensing images have been widely applied in research for LUCC, natural resource management and environment monitoring & protection (Zhang et al., 2014).

Change detection is the identification of variation in land use land cover category based on the observation of a specific area in a different time by using multi temporal data sets from satellite image.in the study by using this method for each year classified images (2016 and 2018),(2016 and 2020)and (2018 and 2020) were analyzed.

4.4.1. Land use land cover change between the years 2016 to 2018.

The result of land use land cover change of the year 2016-2018 showed that the area of bare land and water hyacinth is increased 1% and 2% respectively and the area covered by Papyrus, Shrubs and Water body shows negative change as showed in the following (see Table 4.8).

Table 4.8: Land use land cover change detection of the year 2016 to 2018.

LULC	**2016**		**2018**		**2016-2018**
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)
Bare Land	38114.27	23 %	38627.33	24 %	513.06
Papyrus	5038.68	3 %	4106.00	3 %	-932.68
Shrubs	4850.041	3 %	4178.10	3 %	-671.94
Water Body	113790.78	69 %	111858.87	68 %	-1931.90
Water Hyacinth	2303.49	1 %	5327.26	3 %	3023.77
Total	**164097.83**	**100 %**	**164097.58**	**100 %**	

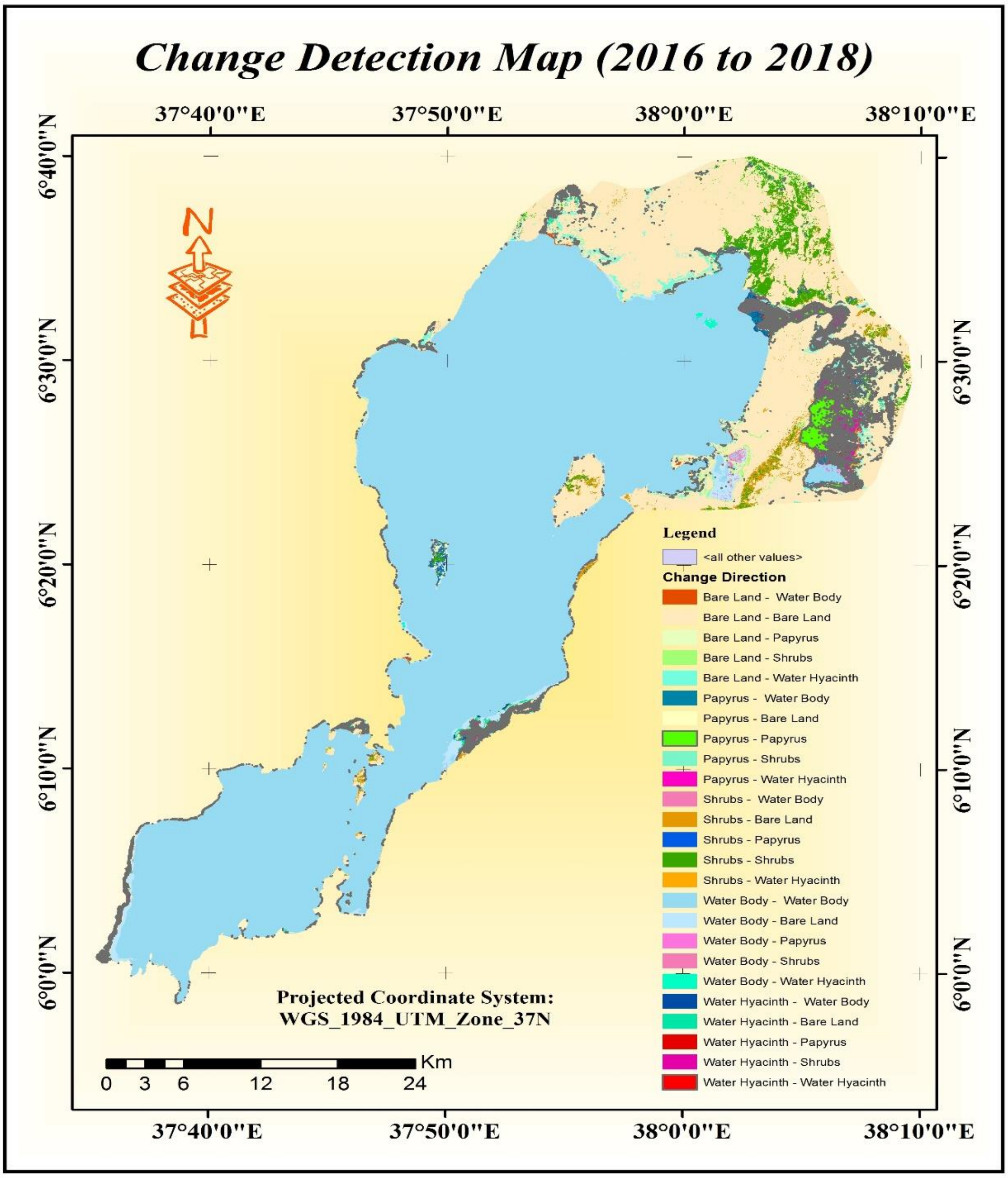


Figure 4.4: Change detection map of study area (2016-2018).

4.4.2. Land use land cover change between the years 2016 to 2020.

Analyses of the result indicated that the area change of water hyacinth is increasing by (3639.13) 3% and the coverage of lake body is increasing and it's constituted large proportion. Generally, the result indicates that bare land, papyrus and shrubs had decreased while water body and water hyacinth had increased (see Table 4.9).

Table 4.9: Land use land cover change detection of the year 2016 to 2020.

LULC	2016		2020		2016-2020
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)
Bare Land	38114.27	23 %	33751.04	21 %	-4363.22
Papyrus	5038.68	3 %	3336.19	2 %	-1702.49
Shrubs	4850.041	3 %	3058.00	2 %	-1792.04
Water Body	113790.78	69 %	118010.10	72 %	4219.32
Water Hyacinth	2303.49	1 %	5942.62	4 %	3639.13
Total	**164097.83**	**100 %**	**164097.97**	**100 %**	

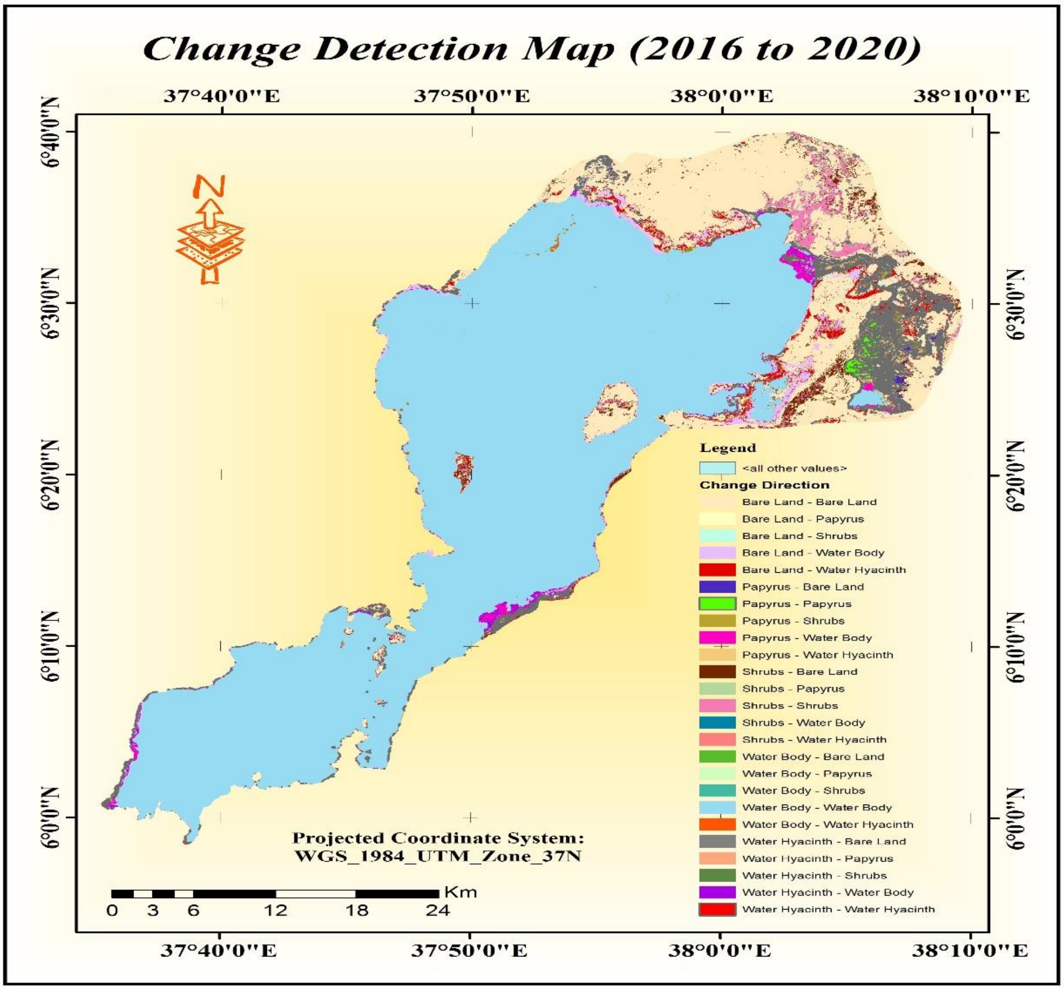


Figure 4.5: Change detection map of study area (2016-2020).

4.4.3. Land use land cover change between the years 2018 to 2020.

Analyses of the result indicated that the area change of water hyacinth is increasing by (615.36) 1% and the coverage of lake body is increasing and it's constituted large proportion. Generally, the result indicates that bare land, papyrus and shrubs had decreased while water body and water hyacinth had increased (see Table 4.10).

Table 4.10: Land use land cover change detection of the year 2018 to 2020.

LULC	2018		2020		2018-2020
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)
Bare Land	38627.33	24 %	33751.04	21 %	-4876.29
Papyrus	4106.00	3 %	3336.19	2 %	-769.81
Shrubs	4178.10	3 %	3058.00	2 %	-1120.10
Water Body	111858.87	68 %	118010.10	72 %	6151.23
Water Hyacinth	5327.26	3 %	5942.62	4 %	615.36
Total	**164097.58**	**100 %**	**164097.97**	**100 %**	

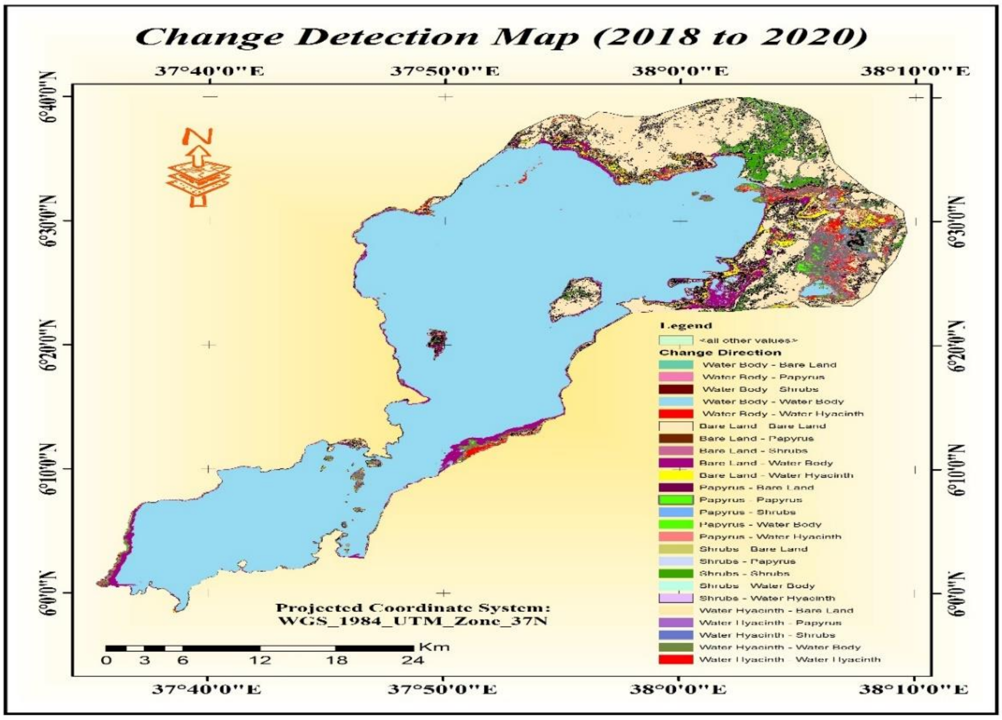


Figure 4.6: Change detection map of study area (2018-2020).

No	Change (2016-2018-2020)	2016-2018 (ha)	2016-2020 (ha)	2018-2020 (ha)
1	Bare Land - Bare Land	33493.44	30139.05	56.42
2	Bare Land - Water Body	167.32	623.17	19.6
3	Bare Land – Papyrus	739.63	596.43	0.11
4	Bare Land – Shrubs	938.28	2894.76	111686.34
5	Bare Land - Water Hyacinth	2765.18	3849.99	96.24
6	Papyrus - Water Body	169.25	651.59	29681.49
7	Papyrus - Bare Land	566.33	2286.77	499.58
8	Papyrus – Papyrus	2938	138.59	586.98
9	Papyrus – Shrubs	69.66	780.78	4861.04
10	Papyrus - Water Hyacinth	1293.3	1178.86	2987.26
11	Shrubs - Water Body	1.26	2101.46	650.9
12	Shrubs - Bare Land	1485.68	275.46	2225.16
13	Shrubs – Papyrus	230.84	2308.28	169.08
14	Shrubs – Shrubs	3043.02	18.42	172.79
15	Shrubs - Water Hyacinth	87.34	144.68	886.81
16	Water Body - Water Body	111382.99	147.48	1289.43
17	Water Body - Bare Land	2081.11	31.35	295.57
18	Water Body – Papyrus	36.27	0.5	2257.29
19	Water Body – Shrubs	117.12	113419.03	186.16
20	Water Body - Water Hyacinth	172.03	191.73	148.82
21	Water Hyacinth - Water Body	137.9	703.24	2064.61
22	Water Hyacinth - Bare Land	989.93	118.81	295.5
23	Water Hyacinth – Papyrus	160.08	13.73	43.96
24	Water Hyacinth – Shrubs	9.28	893.87	1100.52
25	Water Hyacinth - Water Hyacinth	1004.5	572.07	1817.82

Table 4.11: Summary of Change detection the year (2016-2018-2020).

4.5.Discussion

The current study analyzed and map the spatiotemporal distribution of water hyacinth in Lake Abaya and its surroundings using Sentinel-2 MSI satellite data. The extent of coverage rose from 2303.49 ha to 5327.26 ha and subsequently to 5942 ha after a 2-year. The weed is expanding toward the northeastern section of the study area, despite its large coverage. In particular, the result shows that water hyacinth coverage and extension are rapidly expanding, causing harm to the lake's long-term viability. Remote sensing images, are an important free source of information for controlling the spatial and temporal distribution of water hyacinth in Lake Abaya and its surrounding. Furthermore, satellite images are critical for lake management, including invasive species, since they help to understand the dynamics of their growth and expansion.

Sentinel-2 MSI demonstrated the capability of mapping water hyacinth in the study area. The 10 m Sentinel-2 MSI showed its capability in detecting and mapping land cover classes identified in this present study. The generated maps evidenced the Spatio-temporal variation of water hyacinth of Lake Abaya and its surroundings. Besides, it can be observed from the maps that the spatial pattern of water hyacinth.

Moreover, results derived from Sentinel-2 MSI showed the capability of detecting and mapping the spatial distribution of water hyacinth from other land cover classes of the study area. The abovementioned influence the capability of the sensor in detecting and mapping spatial distribution of water hyacinth, which showed satisfactory results with a 90%, 91.55%, 87%, overall accuracy and kappa coefficient of 87.82%, 89.44%, 86%, for the year 2016, 2018 and 2020 respectively. Outcomes of this study concur with previous studies highlighting the capability of using Sentinel-2 MSI in aquatic or vegetation mapping related studies (Youssra et al., 2019).

CAHAPTER V: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The aim of this study was to use Sentinel-2 MSI satellite data to map the spatiotemporal distribution of water hyacinth in Lake Abaya during the dry season. The sentinel-2 MSI satellite, according to this study, opens up new possibilities for mapping and monitoring the seasonal distribution of water hyacinth in an open water system.

Furthermore, satellite images are critical for lake management, including invasive species, since they help to understand the dynamics of their growth and expansion. Satellite imagery is one of the key resources for monitoring change detection. In particular, new-generation Earth observation satellites like Sentinel-2 MSI can be downloaded freely, and coverage maps can be produced at a good temporal resolution. Temporal and spatial analyses of water hyacinth coverage help water resource managers and decision makers to improve water resource management standards.

According to the study result:

- The findings revealed that the coverage of water hyacinth has increased significantly between 2016 and 2020.
- Remote sensing is a very useful resource for establishing a low-cost, effective method of monitoring water body dynamics, such as the expansion and distribution of water hyacinths.
- Sentinel-2 MSI with improved radiometric and spatial resolution detected and mapped the distribution and spatial dynamics of water hyacinth in the water body.
- In general, remote sensing images are an important free source of information for controlling the spatial and temporal distribution of Lake Abaya's water hyacinth.

Overall, the findings of this study add to our understanding of the use of new generation sensors in monitoring aquatic water weeds, and these findings can aid in decision-making and policy formation, as well as the development of remedial methods.

5.2. Recommendations

The findings of this study contribute to a better knowledge of the spatial distribution of water hyacinth and support the use of remote sensing by water or aquatic scientists. These results provide new insights into remote sensing developments and their potential application in aquatic invasive species mapping in water bodies a previously challenging task with broadband multispectral sensors. As a result, a move toward the use of free and widely available sensors with improved sensor properties is required. The following suggestions for future research are made by this study:

1. Rather than threatening all water hyacinth species in the lake, it is necessary to map them individually.
2. It is necessary to determine the amount of water used by various water hyacinth species over time in order to prioritize removal and control efforts.
3. It is recommended that future research be conducted to determine the causes of infestation. The data will be crucial in determining the environmental conditions that encourage the spread of water hyacinth and lower water quality.
4. It is suggested that water hyacinth monitoring be combined with ecosystem modeling research in order to determine the ecological parameters that drive water hyacinth dynamics and better forecast their effects on the fishery.

REFERENCES

Adam, E., Mureriwa, N., & Newete, S. (2017). Mapping Prosopis glandulosa (mesquite) in the semi-arid environment of South Africa using high-resolution WorldView-2 imagery and machine learning classifiers. Journal of Arid Environments, 145, 43–51. https://doi.org/10.1016/j.jaridenv.2017.05.001

Admas A, Sahle S, Belete E, Agidie A, A. M. (n.d.). Controlling water hyacinth in Lake Tana using biological method at green house and pond level. Eur Exp Biol, 2017.

Aplin, P. (2005). Remote sensing: ecology. Progress in Physical Geography: Earth and Environment, 29(1), 104–113. https://doi.org/10.1191/030913305pp437pr

Asmare, E. (2017). Current Trend of Water Hyacinth Expansion and Its Consequence on the Fisheries around North Eastern Part of Lake Tana, Ethiopia. Journal of Biodiversity & Endangered Species, 05(02). https://doi.org/10.4172/2332-2543.1000189

Asner, G. P., Jones, M. O., Martin, R. E., Knapp, D. E., & Hughes, R. F. (2008). Remote sensing of native and invasive species in Hawaiian forests. https://doi.org/10.1016/j.rse.2007.02.043

Balmford A, B. W. (2005). Trends in the state of nature and their implications for human well- being. Ecology Letters, 8, 1218–1234.

Barret, S. C. H., & Forno, I. W. (1982). Style morph distribution in new world populations of Eichhornia crassipes (Mart) SolmsLaubach (water hyacinth). Aquatic Botany, 13, 299–306.

Byrne, M.J., Hill, M.P., Robertson, M., King, A., Jadhav, A., Katembo, N., Wilson, J., Brudvig, R. and Fisher, J. (2010). Integrated management of water hyacinth in South Africa: development of an integrated management plan for water hyacinth control, combining biological control, herbicidal control and nutrient control, tailored to the climatic regions of South Africa. Report to the Water Research Commission, Pretoria, South Africa., 40–44.

Cavalli, R. M., Laneve, G., Fusilli, L., Pignatti, S., & Santini, F. (2009). Remote sensing water observation for supporting Lake Victoria weed management. Journal of Environmental Management, 90(7), 2199–2211. https://doi.org/10.1016/j.jenvman.2007.07.036

Cheruiyot, E., Mito, C., Menenti, M., Gorte, B., Koenders, R. and Akdim, N. (2014). Evaluating MERIS-based aquatic vegetation mapping in Lake Victoria. Remote Sensing, 6(8), 7762–7782.

Drusch, M., Del Bello, U., Carlier, S., Colin, O., Fernandez, V., Gascon, F., Hoersch, B., Isola, C., Laberinti, P., Martimort, P., Meygret, A., Spoto, F., Sy, O., Marchese, F., & Bargellini, P. (2012). Sentinel-2: ESA's Optical High-Resolution Mission for GMES Operational Services. Remote Sensing of Environment, 120, 25–36. https://doi.org/10.1016/j.rse.2011.11.026

Dube, T., Mutanga, O., Sibanda, M., Bangamwabo, V. and Shoko, C. (2017). Evaluating the performance of the newly-launched Landsat 8 sensor in detecting and mapping the spatial configuration of water hyacinth (Eichhornia crassipes) in inland lakes, Zimbabwe. Physics and Chemistry of the Earth, 100, 101–111.

Dube, T., Gumindoga, W., & Chawira, M. (2014). Detection of land cover changes around Lake Mutirikwi, Zimbabwe, based on traditional remote sensing image classification techniques. African Journal of Aquatic Science, 39(1), 89–95. https://doi.org/10.2989/16085914.2013.870068

Dube, Timothy, Mutanga, O., Sibanda, M., Bangamwabo, V., & Shoko, C. (2017). Testing the detection and discrimination potential of the new Landsat 8 satellite data on the challenging water hyacinth (Eichhornia crassipes) in freshwater ecosystems. Applied Geography, 84, 11–22. https://doi.org/10.1016/j.apgeog.2017.04.005

DWAF. (2007). Establishment of a pricing strategy for water use charges in terms of section 56(1) of the National Water Act, 1998. Department of Water Affairs and Forestry, Pretoria.

Emboch on Lake Abaya Prompts Formation of New Committee. (n.d.). Retrieved December 20, 2020, from https://addisfortune.net/articles/emboch-on-lake-abaya-prompts-formation-of-new-committee/

Fessehaie R. (2005). Water hyacinth (Eichhornia crassipes): A Review of its weed status in Ethiopia. Arem (Ethiopia).

Foody, G. M. (2002). Status of land cover classification accuracy assessment. Remote Sensing of Environment, 80(1), 185–201.

Genovesi, P., Carboneras, C., Vila, M. and Walton, P. (2015). EU adopts innovative legislation on invasive species: a step towards a global response to biological invasions? Biological Invasions, 17(5), 1307–1311.

Google Earth. (n.d.). Retrieved December 30, 2020, from https://www.google.com/earth/

Güereña, D. T., Lehmann, J., Thies, J. E., Enders, A., Karanja, N., & Neufeldt, H. (2015). Partitioning the contributions of biochar properties to enhanced biological nitrogen fixation in common bean (Phaseolus vulgaris). Biology and Fertility of Soils, 51(4), 479–491. https://doi.org/10.1007/s00374-014-0990-z

Hansen, J., Sato, M., Ruedy, R., Lo, K., Lea, D. W., & Medina-Elizade, M. (2006). Global temperature change. Proceedings of the National Academy of Sciences, 103(39), 14288–14293. https://doi.org/10.1073/pnas.0606291103

Harding, R. (2004). Social enterprise: The new economic engine? Business Strategy Review, 15(4), 39–43. https://doi.org/10.1111/j.0955-6419.2004.00338.x

Hegazy, I.R and Kaloop, M. R. (2017). Monitoring urban growth and land use change detection with GIS and remote sensing techniques in Daqahlia governorate Egypt. International Journal of Sustainable Built Environment, 39(4), 117–124.

Hestir, Erin L., Khanna, S., Andrew, M. E., Santos, M. J., Viers, J. H., Greenberg, J. A., Rajapakse, S. S., & Ustin, S. L. (2008). Identification of invasive vegetation using hyperspectral remote sensing in the California Delta ecosystem. Remote Sensing of Environment, 112(11), 4034–4047. https://doi.org/10.1016/j.rse.2008.01.022

Hestir, Erin Lee, Brando, V. E., Bresciani, M., Giardino, C., Matta, E., Villa, P., & Dekker, A. G. (2015). Measuring freshwater aquatic ecosystems: The need for a hyperspectral global mapping satellite mission. Remote Sensing of Environment, 167, 181–195. https://doi.org/10.1016/j.rse.2015.05.023

Jensen, J. R. (2000). An earth resource perspective. Remote Sensing of the Environment, 72, 361–365.

John, C. M., & Nath, K. (2014). Integration of multispectral satellite and hyperspectral field data for aquatic macrophyte studies. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, XL–8(1), 581–588. https://doi.org/10.5194/isprsarchives-XL-8-581-2014

Kganyago, M., Odindi, J., Adjorlolo, C. and Mhangara, P. (2018). Evaluating the capability of Landsat 8 OLI and SPOT 6 for discriminating invasive alien species in the African

Savanna landscape. International Journal of Applied Earth Observation and Geoinformation, 67, 10–19.

Kushwaha, S. P. S. (2012). Remote sensing of invasive alien plant species.

Lindsey, K. and Hirt, H.-M. (1999). Use water hyacinth! A practical handbook of uses for the water hyacinth from across the world. Marianum Press, Kisubi, Uganda.

Masocha, M. and Skidmore, A. K. (2011). Integrating conventional classifiers with a GIS expert system to increase the accuracy of invasive species mapping. International Journal of Applied Earth Observation and Geoinformation, 13(3), 487–494.

Mengist, Y., & Moges, Y. (2019). Distribution, Impacts and Management Option for Water Hyacinth (Eichhnornia Crassipes [Mart.] Solms) in Ethiopia: A Review. Journal of Advances in Agriculture, 10, 1764–1771. https://doi.org/10.24297/jaa.v10i0.8308

Mengistu, B. B., Unbushe, D., & Abebe, E. (2017). Invasion of Water Hyacinth (<i>Eichhornia crassipes</i>) Is Associated with Decline in Macrophyte Biodiversity in an Ethiopian Rift-Valley Lake—Abaya. Open Journal of Ecology, 07(13), 667–681. https://doi.org/10.4236/oje.2017.713046

Mesev, V. (2010). Classification of urban areas: inferring land use from the interpretation of land cover. Remote Sensing of Urban and Suburban Areas, 141–164.

Mostert, E., Gaertner, M., Holmes, P.M., Rebelo, A.G. and Richardson, D. M. (2017). Impacts of invasive alien trees on threatened lowland vegetation types in the Cape Floristic Region, South Africa. South African Journal of Botany, 108, 209–222.

Mukarugwiro, J. A., Newete, S. W., Adam, E., Nsanganwimana, F., Abutaleb, K. A., & Byrne, M. J. (2019). Mapping distribution of water hyacinth (Eichhornia crassipes) in Rwanda using multispectral remote sensing imagery. African Journal of Aquatic Science, 44(4), 339–348. https://doi.org/10.2989/16085914.2019.1650712

Negassa Dechassa, B. A. (2021). Current Status of Water Hyacinth (Eichhornia crassipes) in Ethiopia : Current Status of Water Hyacinth (Eichhornia crassipes) in Ethiopia : Achievements , Challenges and Prospects : A Review. January. https://doi.org/10.7176/JEES/10-12-03

Ongore, C. O., Aura, C. M., Ogari, Z., Njiru, J. M., & Nyamweya, C. S. (2018). Spatial-temporal dynamics of water hyacinth, Eichhornia crassipes (Mart.) and other macrophytes and their impact on fisheries in Lake Victoria, Kenya. Journal of Great

Lakes Research, 44(6), 1273–1280. https://doi.org/10.1016/j.jglr.2018.10.001

Parsons, W.T., Parsons, W.T. and Cuthbertson, E. G. (2001). Noxious weeds of Australia. CSIRO Publishing, Australia.

Patel S: (2012). Threats, management and envisaged utilizations of aquatic weed Eichhornia crassipes: an overview. Reviews in Environmental Science and Bio/Technology, 11, 249–259.

Penatti, N. C., Almeida, T. I. R. de, Ferreira, L. G., Arantes, A. E., & Coe, M. T. (2015). Satellite-based hydrological dynamics of the world's largest continuous wetland. Remote Sensing of Environment, 170, 1–13. https://doi.org/10.1016/j.rse.2015.08.031

Perna, C. and Burrows, D. (2005). Improved dissolved oxygen status following removal of exotic weed mats in important fish habitat lagoons of the tropical Burdekin River floodplain, Australia. Marine Pollution Bulletin, 51(1-4), 138–148.

Piyaboon, O., Pawongrat, R., & Unartngam, J. (2016). Pathogenicity, host range and activities of a secondary metabolite and enzyme from Myrothecium roridumon water hyacinth from Thailand. Weed Biology and Management, 16, 132–144.

Rands, M.R., Adams, W.M., Bennun, L., Butchart, S.H., Clements, A., Coomes, D., Entwistle, A., Hodge, I., Kapos, V., Scharlemann, J.P. and Sutherland, W. J. (2010). Biodiversity conservation: challenges beyond 2010. Science, 329(5997), 1298–1303.

Rift Valley Lakes Basin Authority - ጉግል መድለይ. (n.d.). Retrieved December 23, 2020, from https://www.google.com/search?q=Rift+Valley+Lakes+Basin+Authority&oq=Rift+Valley+Lakes+Basin+Authority&aqs=chrome..69i57.2745j0j15&sourceid=chrome&ie=UTF-8

Rogers, W. E. (2018). Invasive Species. Encyclopedia of the Anthropocene. 273–280.

Scanes, C. G. (2018). Invasive Species. In Animals and Human Society, 413–426.

Shekede, M. D., Kusangaya, S., & Schmidt, K. (2008). Spatio-temporal variations of aquatic weeds abundance and coverage in Lake Chivero, Zimbabwe. Physics and Chemistry of the Earth, 33(8–13), 714–721. https://doi.org/10.1016/j.pce.2008.06.052

Singh, A. (1986). Digital Change Detection Techniques using Remotely Sensed Data. 10(6), 989–1003.

Taye T, Rezene F, Firehun Y, Derje T, T. T. (2009). Increasing crop production through improved plant protection. Review Invasive Weed Research in Ethiopia, 2, 381–407.

Téllez, T. R., López, E. M. de R., Granado, G. L., Pérez, E. A., López, R. M., & Guzmán, J. M. S. (2008). The water hyacinth, Eichhornia crassipes: An invasive plant in the Guadiana River Basin (Spain). Aquatic Invasions, 3(1), 42–53. https://doi.org/10.3391/ai.2008.3.1.8

Tewabe, D. (2015). Preliminary Survey of Water Hyacinth in Lake. Global Journal of Allergy, 1(1), 013–018. https://doi.org/10.17352/2455-8141.000003

Thamaga, K.H. and Dube, T. (2018). Remote sensing of invasive water hyacinth (Eichhorniacrassipes): A review on applications and challenges. Remote Sensing Applications: Society and Environment, 10, 36–46.

Thamaga, K. H., & Dube, T. (2018a). Remote sensing of invasive water hyacinth (Eichhornia crassipes): A review on applications and challenges. Remote Sensing Applications: Society and Environment, 10(February), 36–46. https://doi.org/10.1016/j.rsase.2018.02.005

Thamaga, K. H., & Dube, T. (2018b). Remote sensing of invasive water hyacinth (Eichhornia crassipes): A review on applications and challenges. Remote Sensing Applications: Society and Environment, 10, 36–46. https://doi.org/10.1016/j.rsase.2018.02.005

Underwood, E. C., Mulitsch, M. J., Greenberg, J. A., Whiting, M. L., Ustin, S. L., & Kefauver, S. C. (2006). Mapping invasive aquatic vegetation in the sacramento-san Joaquin Delta using hyperspectral imagery. Environmental Monitoring and Assessment, 121(1–3), 47–64. https://doi.org/10.1007/s10661-005-9106-4

UNEP. (2013). Water hyacinth—Can its aggressive invasion be controlled? Environmental Development.

Villamagna, A.M. and Murphy, B. R. (2010). Ecological and socio-economic impacts of invasive water hyacinth (Eichhornia crassipes): A Review. Freshwater Biology, 55(2), 282–298.

Wilson, J. R., Holst, N., & Rees, M. (2005). Determinants and patterns of population growth in water hyacinth. Aquatic Botany, 81(1), 51–67. https://doi.org/10.1016/j.aquabot.2004.11.002

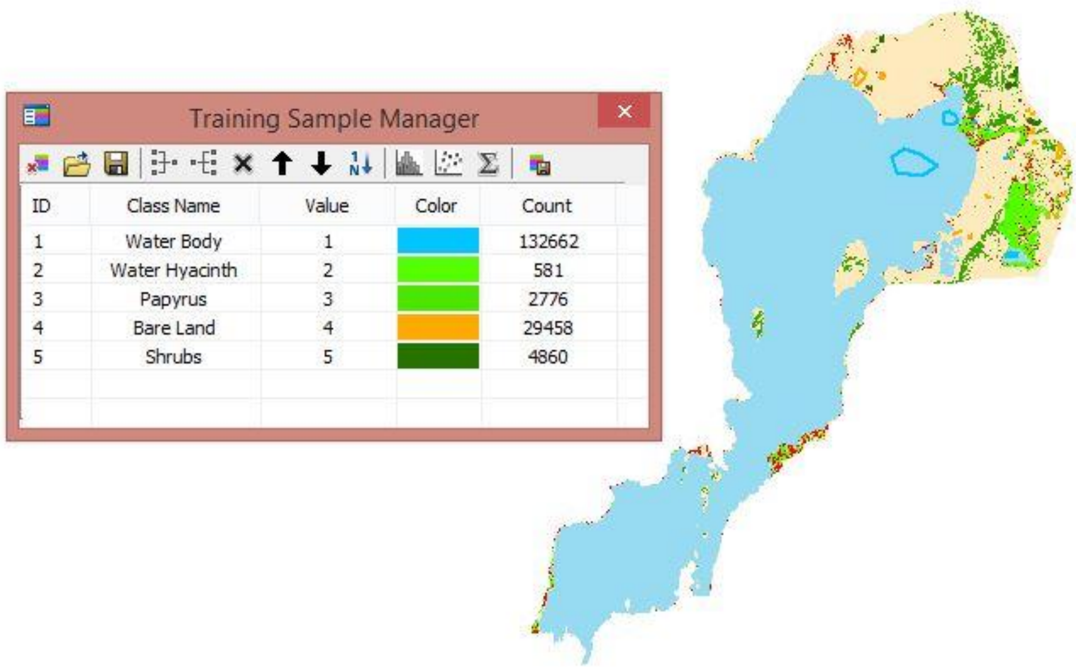
Xu, H., Qiang, S., Genovesi, P., Ding, H., Wu, J., Meng, L., Han, Z., Miao, J., Hu, B., Guo, J., Sun, H., Huang, C., Lei, J., Le, Z., Zhang, X., He, S., Wu, Y., Zheng, Z., Chen, L., … Pysek, P. (2012). An inventory of invasive alien species in China. NeoBiota, 15, 1–26. https://doi.org/10.3897/neobiota.15.3575

Zhang, C., Smith, M., Lv, J., Fang, C. (2017). Applying time series Landsat data for vegetation change analysis in the Florida Everglades Water Conservation Area 2A during 1996–2016. International Journal of Applied Earth Observation and Geoinformation, 57, 214–223.

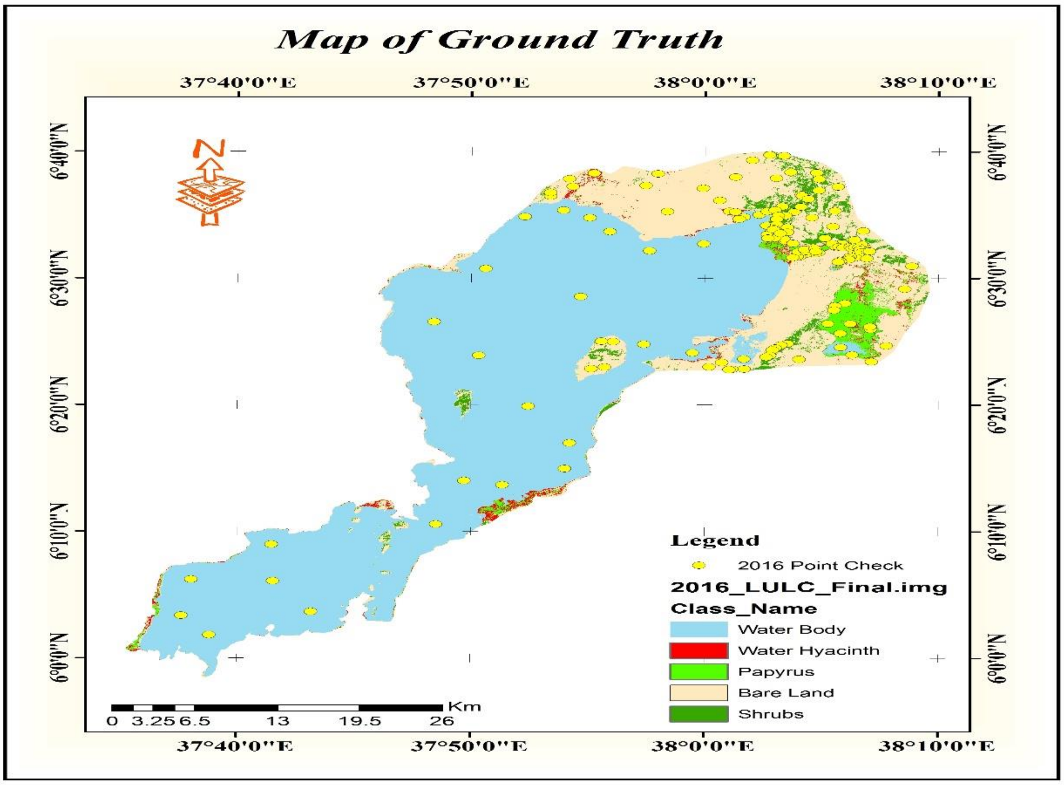
Zhang YY, Zhang DY, B. S. (2010). Genetic uniformity characterizes the invasive spread of water hyacinth (Eichhornia crassipes), a clonal aquatic plant. Molecular Ecology, 19, 1774–1786.

APPENDICES

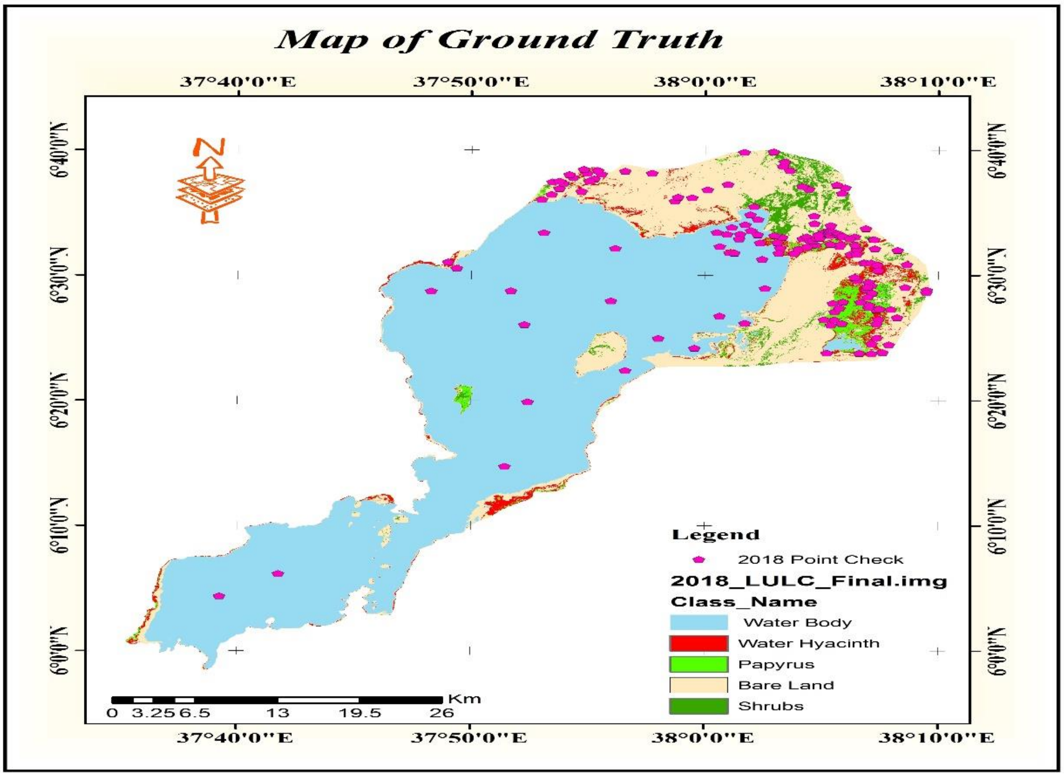
Appendix 1: Identification of training sites using sentinel image (ArcGIS 10.8).



Appendix 2: 2016 classification map of Ground Truth.



Appendix 3: 2018 classification map of Ground Truth.



Appendix 4: 2020 classification map of Ground Truth.