ASSESSING THE EFFECTS OF WATER HYACINTH ON THE PHYSICO-CHEMICAL WATER QUALITY IN MURCHISON BAY- LAKE VICTORIA BASIN, UGANDA

BY

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DECLARATION

I hereby declare that this dissertation is my original work and has not been presented to any other University for any other degree award.

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APPROVAL

We hereby certify that this dissertation has been prepared under our supervision and is now ready for submission with our approval.

Signature: ………………………………………… Date…………………………...

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DEDICATION

I dedicate this piece of work to my mum Hajjat Najjuma Nuriat, my wife Nalubowa Rukia and my children; Rayan, Hussein junior, Nuriat, Isma, and Arkam.

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ACRONYMS

ANOVA: Analysis of Variance

BOD: Biochemical Oxygen Demand

COD: Chemical Oxygen Demand

DA: Discriminant Analysis

DO: Dissolved Oxygen

GIS: GIS Geographic Information Systems

IRSS: Indian Remote Sensing Satellite

IUCN: International Union for Conservation of Nature

NTU: Naphelometric Turbidity Units

NWSC: National Water and Sewerage Corporation

TP: Total Phosphates

UBOS: Uganda Bureau of Statistics

UN: United Nations

UNEP: United Nations Environment Program

USGS: United States Geological Survey

UTM: Universal Transverse Mercator

WHO: World Health Organization

WRM: Water Resource Management

ABSTRACT

Despite its aggressive nature the water hyacinth, its extent and impact on water quality is not well documented. This study involved mapping the extent and pattern of water hyacinth between 2016 and 2019, determining the effect of water hyacinth on physico-chemical properties of water, and establishing the perceived determinants of water hyacinth extent and distribution pattern in Murchison Bay on Lake Victoria. A cross-sectional study design was adopted for the study following both qualitative and quantitative approaches. Sentinel 2A images of the study area for the period, 2016-2019 were used to map the water hyacinth extent and distribution pattern. 10 pairs of water-sampling point locations were determined for water sampling in areas with water hyacinth and those from open lake at an average distance of 500 meters from each sampling point. Respondents (201) were also sampled (purposively) from the landing sites of Ggaba, Port Bell and Mulungu, comprising of fishermen, traders, fisheries officers, officials from national water, and local residents. The respondents were asked to rate 15 factors on a scale of 1- 4 to show the extent to which they believed determined extent and pattern of distribution of water hyacinth. A Two-way ANOVA was conducted to determine the effect of sampling environment and depth on water quality parameters. The results that in 2016, water hyacinth covered a land area of 511 km^2 (1%) which increased to 2,434 km^2 (4%) in 2017. The coverage dropped to 1,542 km^2 (3%) in 2018. The coverage increased again in 2019 to 2138 km^2 (4%). The two-way ANOVA results indicated significant effect of sampling environment on pH, DO, COD, BOD, Turbidity, TP and Transparency but not EC, and temperature. The effect of sampling depth was only significant on pH, EC, BOD and DO while the interactive effect of environment and depth was insignificant for all water quality parameters. From the socio-economic data, sewerage effluent discharge, blowing of local winds and path of Ferry Navigation were perceived as key determinants of water hyacinth distribution. It was concluded that: (i) the extent and distribution of water hyacinth in Murchison Bay varies over space and time but concentration is mainly on the northern shores, (iii) Water hyacinth significantly affects water quality, in some cases beyond the WHO maximum permissible limits for human consumption, and the perception of the determinants of water hyacinth extent and distribution vary across Murchison Bay. Therefore, water resources management departments in the country should put up practical measures to control proliferation of the water hyacinth on water bodies. Future research should focus on long-term monitoring of water quality parameters with reference to water hyacinth infestation.

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

Water hyacinth is a free-floating perennial aquatic monocotyledonous plant belonging to a family pontederiaceae (Bhattacharya et al., 2015). The plant has proven to be a significant economic and ecological burden to many sub-tropical and tropical regions (Asmare, 2017). Water hyacinth has been listed as one of the most productive plant on earth, which has invaded fresh water systems in over 50 countries on five continents, especially throughout South East Asia, the South East United States, Central and Western Africa and Central America (Mako et al., 2011; Mironga et al., 2012; Havel et al., 2015). Water hyacinth is efficient in utilizing aquatic nutrients and solar energy for profuse biomass production causing extensive environmental, social and economic problems (Robles et al., 2015; Shoko & Mutanga et al., 2017). The water hyacinth commonly inhabits lakes and estuaries, wetlands, marshes, ponds, slow flowing streams, rivers and waterways in lower latitudes where growth is stimulated by the inflow of nutrient rich water from urban and agricultural runoff, deforestation, products of industrial wastes and insufficient waste treatment (Villamagna & Murphy, 2010). Today the water hyacinth is naturalized in many areas of the world including South America, Asia, Australia, India, News Zealand and Africa (Patel, 2012; Havel et al., 2015).

In Uganda, water hyacinth was first reported on Lake Kyoga in 1988 and on Lake Victoria in 1989 (Albright, 2004). The weed is believed to have migrated from the Nile basin in Egypt to Sudan. It later appeared in the upper Nile Basin in Kyoga during the late 1980s and in Lake Victoria at about the same time (Gichuki et al., 2012). The weed mainly concentrated at sheltered mouth of rivers like Katonga and sheltered Bays (Asmare et al., 2017; Villamagna & Murphy, 2017). Kitunda (2003) reports the strong influence of the South Easterly and Southerly prevailing winds in the Southern portion of Lake Victoria from June through December to February are responsible for the migration of the water hyacinth. The wind pattern therefore explains the dumping of most of the water hyacinth from River Kagera on the Ugandan Shores of Lake Victoria.

The threats presented by the water hyacinth are mainly due to the characteristics of the plant. Water hyacinth is one of the 100 most aggressive invasive species (Tellez et al., 2008; Thamaga and Dube, 2018; Shoko & Mutanga, 2017) and it is recognized as one of the 10 worst weeds in the world (Shanab et al., 2010; Gichuki et al, 2012; Patel, 2012). It is characterized by rapid growth rates, extensive dispersal capabilities, large and rapid reproductive output and broad environmental tolerance (Porter et al., 2013). In Africa, water hyacinth is the most widespread and damaging aquatic plant species and as such, the plant is listed as a noxious weed in several countries. The economic impacts of the weed in East, Central and Southern Africa has been estimated at USA $ 20-50 million per year in some instances it could be as high as USA $ 100 million annually (Sharma et al., 2005: Pimentel et al., 2005).

The distribution of these macrophytes is related to the speed of water. The floating form of this plant does not take roots so that it is exposed to kinetic action of the water currents. To be able to constitute a stable population, it requires the support of macrophytes or helophytes (rush and reed beds) on which to anchor (Téllez et al., 2008: Xu et al., 2012). Since the currents facilitates the dispersal of propagules and stalons and hence the colonization of new areas (Bhattacharya et al., 2015). Similarly, the depth of the water and changes in Lake water level are important for the growth and expansion of water hyacinth (Zhang et al., 2010: Ndimele et al., 2011; Khanna et al., 2011; Patel, 2012). Furthermore, the plant has more roots when they are floating in deep water than in shallow waters (the water hyacinth expansion is also related to the level of eutrophication). That is, the proliferation is high in highly polluted environments (Shanab et al., 2010; Patel, 2012).

Water hyacinth degrades and chokes freshwater ecosystems, compromising the quality of water and threatening the quality of life (Wondie, 2013 Thamaga and Dube, 2019). Early detection and up to date information regarding its distribution is therefore crucial in understanding its spatial configuration and propagation rate (Kutser et al., 2015; Hestir et al., 2015). Recently the rate and risk linked with aquatic weeds has notably increased in most inland freshwater ecosystems (Carpenter et al., 2011). This is attributed to climate change, increased nutrient enrichment, as well as other organic and inorganic pollutants from various anthropogenic activities (Porter et al., 2013). Despite threats posed by these weeds, as well as their relative increase in spatial coverage, which calls for urgent monitoring and management efforts; their spatial distribution and configuration remains poorly quantified and understood especially in less developed economies (Dube et al., 2014; Thamaga and Dube, 2018;).

Dube (2014) argues that monitoring and mapping of spatial configuration of water hyacinth is necessary to provide essential information for proper mitigation and control and ensure continued provision of goods and services by the water bodies under such threat. This is made possible with help of remote sensing and Geographical Information Science technologies. These technologies possess great potential and ability to study and map landscape features like vegetation for timely assessment and inventory of such resources (Robles et al., 2015; Matongera et al., 2017). The current study was therefore undertaken to provide information concerning the extent and pattern of water hyacinth distribution, which is required to determine its severity through time, relate the abundance of the weed to the environmental factors, and identify threats to water quality.

Water is an irreplaceable and indispensable natural resource, vital for life on earth, economic development and human well-being (Forslund et al., 2009; Thamaga et al., 2018). Water quality problems related to pollution is currently the principal challenge to water resources management globally (Lawson, 2011). Water is considered to be polluted if it cannot be used for a particular purpose, because of the physical, chemical and biological degradation as it moves through the spheres of the hydrological cycle (Dugan, 2012). Water quality is defined in terms of the chemical, physical and biological content of water (Tyagi et al., 2013; Spellman, 2013; Shah, 2017). Many factors including, water hyacinth, runoff, nitrification from decayed matter, toxic, hazardous substances, Oils, grease, litter, and rubbish and land uses like industrialization, farming, mining and forestry activities significantly contribute to water quality degradation (Bhattacharya et al., 2015). Farming can increase the concentration of nutrients and suspended sediments; industrial activities can increase the metals and toxic chemicals in the water. Suspended sediments and dissolved matter make water unsuitable for established or potential purposes (Dezuane, 1997: Moreno et al., 2009). Water hyacinth has potential to degrade the quality of water through biological pollution due to its ability to alter nutrient cycles and its impact on aquatic life (Asmare et al., 2016; Matongera et al., 2017). This justified the need for the study.

1.2 Statement of the Problem

The Murchison Bay is the main water supply source for domestic and industrial purposes in Kampala and the neighboring districts of Mukono, and Wakiso. The Bay supports diverse recreational activities including; angling, boat fishing but also acts as the main inland port in Uganda thus promoting development (Akurut et al., 2014). Despite the contribution to the development of Kampala city and the surrounding areas of Mukono and Wakiso, Murchison Bay faces threats of stern pollution, which has persisted for over two decades. Much of the water pollution on Lake Victoria has been attributed to anthropogenic factors like sewerage effluent, nitrification from agricultural fields and industrial waste effluent (Haande et al., 2011). However, the fact that the Murchison Bay has been invaded by the water hyacinth implies that the weed could provide some explanation to the increasing deterioration in the quality of water in it. The color and odor of water in the Bay especially at points infested by the water hyacinth is a clear indication that the weed could be affecting the quality of water. Akurut (2011) reports that the water treatment costs by National Water and Sewage Corporation (NWSC) have trebled in the last two decades owing to the fluctuating lake water levels and deteriorating water quality in the Murchison Bay, which has threatened the capacity to increase water production for the increasing population of Kampala city. Increased water production costs imply increase in water prices thus making it unaffordable to the urban poor in Kampala, Wakiso and Mukono (Haande et al., 2011). In 2010, the United Nations recognized the right to safe and clean water and sanitation as basic human rights, as they are indispensable to sustaining health livelihoods and fundamental in maintaining the dignity of all human beings. However, there is limited documented evidence in Murchison Bay to show the distribution of water hyacinth and its effect on the quality of water. Previous studies in the Bay have focused on Urban eutrophication and its spurring conditions in the Murchison bay, socio-economic impact of water quality deterioration and impact of sewerage effluent on water quality in the Bay (Haande et al., 2011; Akurut et al., 2014:Kabenge et al.,2016). It was therefore imperative to map the distribution and assess the effect of this alien aquatic plant species on the quality of water in the Bay, such that appropriate control and management measures are implemented to keep contamination at unproblematic levels.

1.3 Main Objective

The overall objective of this study was to analyze the effects of water hyacinth on water quality in Murchison Bay - Lake Victoria.

1.4 Specific Objectives

i. To map the extent and pattern of water hyacinth between 2016 and 2019 in the Murchison Bay, Lake Victoria.
ii. To determine the effect of water hyacinth on the physico-chemical properties of water in the Murchison Bay, Lake Victoria.
iii. To establish the determinants of water hyacinth pattern and distribution over time in the Murchison Bay, Lake Victoria.

1.5 Research Questions

1. What is the extent and pattern of water hyacinth in the Murchison Bay?
2. What are the perceived biophysical and social-economic determinants of water hyacinth pattern and distribution in the Murchison Bay?
3. What is the effect of water hyacinth on the physico-chemical properties of water in the Murchison Bay?
4. What is the variation of physico-chemical properties of water with depth in the Murchison Bay?

1.6 Research Hypotheses

There is no significant difference in the determinants of water hyacinth pattern and distribution across Murchison Bay.

Water hyacinth and water depth have no significant effect on the quality of water in Murchison Bay.

1.7 Significance of the Study

The mapping of the current extent and pattern of water hyacinth in the Murchison Bay will provide essential information on water hyacinths hotspots and the emerging water quality issues such that these are targets for intervention and mitigation to conserve the quality of water in the Bay.

The research findings on physico-chemical water quality properties will be useful to the relevant Government agencies such as NWSC, NEMA; international agencies such as WHO, and other stakeholders in designing workable strategies for curbing the eutrophication levels of the Murchison Bay.

The study findings will add unto the existing body of knowledge on water resources threats, water quality and management strategies for future research needs and reference. This will be useful to scholars and researchers.

1.8 Scope of the Study

This study was conducted in Murchison Bay on the Northern parts of Lake Victoria. The Bay was selected for the study due to its usefulness as a main water supply point for the population of over 4 million people living in the districts of Kampala, Wakiso, and Mukono. The study covered mainly the inner Murchison Bay. In terms of study content, this study was restricted to mapping of the spatial extent and pattern of the water hyacinth, assessment of perceived determinants of water hyacinth distribution, and effects of the weed on the physico-chemical water quality properties. Data for mapping of water hyacinth extent and pattern stretched for a period of four years (i.e. from 2016 to

2019), field data on perceived determinants of water hyacinth distribution were collected between November and December 2019 whilst water samples for physico-chemical properties testing was collected between September 2019 and March, 2020. Field water sampling was done two times taking an interval of one month.

1.9 Conceptual Framework

In this study, it is hypothesized that water quality as measured by physico-chemical properties; Dissolved Oxygen,pH, Total Phosphates, Biochemical oxygen demand, Turbidity, Transparency, Electrical Conductivity, Temperature and Chemical Oxygen Demand; related to water hyacinth proliferation meaning these water quality properties are different between water hyacinth infested and non-water hyacinth infested water environments. However, there are other factors that affect water quality parameters for example, industrial and sewerage effluent, Nutrient loading from agricultural fields (fertilizers), flood storms and sedimentation. The conceptual framework in this study demonstrates the links between water hyacinth and water quality (Figure 1.1).

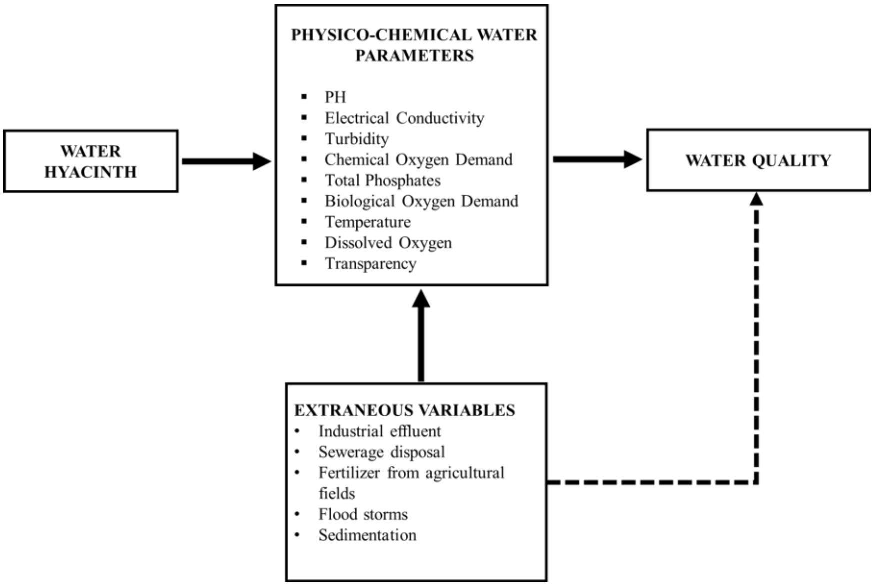

Figure 1.1: Conceptual framework adopted in the study

From Figure 1.1, water quality is conceptualized as the dependent variable whereas water hyacinth is conceptualized as independent variable. The relationship between water hyacinth and water quality is modulated by other factors like industrial effluent, sewerage disposal, fertilizer use from agricultural fields, flood storms and sedimentation, which are hypothesized as intervening variables.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This chapter presents a review of existing related literature on water hyacinth and water quality in open water systems. The literature is reviewed according to the study objectives spelt out in chapter one.

2.1 Water hyacinth and its global distribution

Water hyacinth has been listed as one of the most productive plant on earth, which has invaded fresh water systems in over 50 countries on five continents, especially throughout South East Asia, the south east united states, central and western Africa and Central America. Water hyacinth forms dense impenetrable mats across water surfaces that greatly decrease biodiversity. It degrades water quality and limits access by humans, machinery, animals and birds (Tegene & Ayele, 2014). Water hyacinth also has a large evapotranspiration rate losing water into the atmosphere at up to six times that lost by open water (Asmare et al., 2016).

The water hyacinth is efficient in utilizing aquatic nutrients and solar energy for profuse biomass production causing extensive environmental, social and economic problems (Kitunda, 2003: Porter et al., 2013). It is formed in lake sand estuaries, wetlands, marshes, ponds, dambos, slow flowing rivers, streams and waterways in lower latitudes where growth is stimulated by the inflow of nutrient rich water from urban and agricultural runoff, deforestation, products of industrial wastes and insufficient waste treatment (Gichuki et al., 2012; Asmare et al., 2017; Villamagna & Murphy, 2010). The family; Pontederiaceae has nine genera including *Eichhornia*, which has eight species of freshwater aquatics including water hyacinth (*Eichhornia crassipes*). Only *E. crassipes* is regarded as a pan-tropical aquatic weed (Xu et al., 2012). The name water hyacinth refers to its aquatic habitat and the similarity of the flower colour to that of the garden hyacinth (Downing-Kunz & Stacey, 2012). Water hyacinth, a free-floating macrophyte, live at the air-water interface and form two distinct canopies: leaf canopies comprising above-water structures and root canopies comprising below water structures (Downing-Kunz & Stacey, 2012; Opande et al., 2017).

The English common names of the plant are water hyacinth, and Water hyacinth is the standardized spelling adopted by the Weed Science Society of America to denote that it is not an aquatic relative of true "hyacinth" (*Hyacinthus* spp.). Synonyms are *Eichhornia crassipes* (Mart. and Zucc.) Solms, *Pontederia crassipes* (Mart. and Zucc.), *Piaropus crassipes* (Mart. and Zucc.) Britton (Penfound & Earle, 1948).

Today the water hyacinth has become naturalized in many areas of the world including South America, Asia, Australia, India, News Zealand and Africa. It grew at a rate 2x10 hectares per year, spreading at an alarming rate, its entry into North America, Asia, Europe and Africa was facilitated by human activities (Gichuki et al., 2012). Along with the United States, 50 other countries have reported the water hyacinth as a noxious weed. Its geographical distribution also includes Indo-china and Japan (Havel et al., 2015).

Within the United States E., Cassipses occurs throughout the South East, north to Virginia and west to Texas as well as in California and Hawaii. Reports indicates that in California (USA) this weed has caused severe ecological impact in the sacrament, in Mexico, more than 40,000 hectares of reservoirs, lakes, and canal are infested with water hyacinth, Villamagna and Murphy (2010). In Europe, water hyacinth is established locally in France, Italy and casual records are known from Belgium, the Czech Republic, Hungary, the Netherland and Romania. In particular its threat to Spain and Portugal (EEA, 2012: Scalera et al., 2012).

In the countries of South America, there are reports of its presence in Brazil 1902, Argentina in 1942, Paraguay in 1959, Uruguay, Bolivia, Ecuador, and Colombia, 1976, Venezuela. It was introduced into Asia at the end of the 20th century through Japan and Indonesia and become naturalized in rice fields in the south and gradually extending northwards (Bhattacharya et al., 2015). In Indonesia, there are references to its appearance in Bogor where it was grown as an ornamental in Botanical gardens (Khanna et al., 2012; Shoko.c. & Mutanga et al., 2017).

In India it first appeared in Bengal at the beginning of 1890 and is now present throughout the country except in the more arid part of Rajasthan, and curtly it has been cited in Taiwan (GISD, 2005) and mainland china (Porter et al., 2013). The water hyacinth introduction into Australia and Oceania occurred in 1890 near Darwin (Northern Territories). Today it exists in the coastal areas of all federated states of Australia and has also appeared in many islands of the Pacific Ocean (EEA, 2012).

In West Africa, water hyacinth was first reported in Cameroon between 1997 and 2000 and since then the country's wetlands have become home for the weed (Bicudo et al., 2007). In Nigeria almost all river bodies have been dominated by water hyacinth (Cho & Tifuh, 2012). The water hyacinth problem is especially severe on the Niger River in Mali where human activities and livelihoods are closely linked to the water systems.

It occurs throughout the Nile Delta in Egypt and is believed to be spreading southward, due to the Construction of the Aswan Dam which has slowed down the river flow enabling the weed to invade. Infestation of water hyacinth in Ethiopia has also been manifested on a large scale in many water bodies of the Gambella area, Lake Ellen in the rift valley and Lake Tana (Fessehaie, 2012).

In Uganda water hyacinth was first reported in Lake Kyoga in 1988 (Albright, 2004) and later it was reported in Lake Victoria in 1989. Kitunda(2003) report that the weed migration from Nile basin in

Egypt to Sudan in the early of the Zone and later appeared in the upper Nile Basin in Kyoga during the late 1980s and in Lake Victoria at about the same time. The weed mainly concentrated at sheltered mouth of rivers like Katonga and sheltered Bays. The weed was moving under the influence of the Southeasterly prevailing winds. Albright (2004) observed the strong influence of the South Easterly and southerly prevailing winds in the Southern portion of Lake Victoria from June through December to February. This wind pattern would explain the dumping of most of the water hyacinth from River Kagera on the Ugandan Shores of Lake Victoria(Kateregga & sterner,2007).

2.2 Mapping the extent and pattern of water hyacinth

Water hyacinth is one of the most aggressive floating aquatic plant that degrades and chokes freshwater ecosystems, compromising the quality of water and threatens the quality of life. Early detection and up to date information regarding its distribution is therefore crucial in understanding its spatial configuration and propagation rate (Kutser et al., 2015; Giardino et al., 2015). Recently the rate and risk linked with aquatic weeds has notably increased in most inland freshwater ecosystems, because of climate change, increased nutrient enrichment, as well as other organic and inorganic pollution from various anthropogenic activities (Porter et al., 2013). However, despite threats posed by these weeds, as well as their relative increase in spatial coverage, which calls for urgent monitoring and management efforts; their spatial distribution and configuration remains poorly quantified and understood especially in less developed economies (Thamaga and Dube, 2018).

Remote sensing technologies have played a critical role in detecting, discriminating, mapping and monitoring the distribution of water hyacinth in large water bodies (Matongera et al., 2017). The increase in the use of remote sensing data in mapping invasive species is linked to its ability to offer a variety of new applications that can quickly and synoptically monitor and manage large areas. For example, remote sensing has permitted a timely and inventory assessment of aquatic weeds, environmental hazards, natural resources and water quality monitoring(Manfreda,Salvatore et al.,2018). Satellite data can capture the spatial and temporal distribution of aquatic macrophytes in a timely and cost-effective approach (Hestir et al., 2008; Shekede et al., 2008). Furthermore, continual coverage of satellite sensors provides spatial data for both short and long-term monitoring, which is crucial in identifying and assessing the strengths of the control measures in place. Different spectral bands and vegetation indices from different sensors have been tested in mapping the spatial distribution of water hyacinth (Cheruiyot et al., 2014; Matongera et al., 2017; Shoko and Mutanga, 2017). Shoko and Mutanga (2017) examined the strength of the newly launched Sentinel-2 MSI sensor in detecting and discriminating subtle differences between C3 and C4 grass species.

Satellite data have become the principal source of spatial information on the extent and propagation of aquatic weeds, replacing traditional field surveys (Hestir et al., 2008; Hestir et al., 2015). This is due to its fast revisit time frequency, which provides observations over large spatial scales in near real time, especially in areas where in-situ networks are sparse. Sensors with high spatial, spectral temporal radiometric resolutions are needed for accurate ecological monitoring to understand water hyacinth extent and distribution (Matongera et al., 2017).

Shoko and Mutanga (2017), showed that Sentinel-2 with improved Image acquisition and sensing characteristics provides renewed capability for vegetation mapping and monitoring. Sentinel-2 MSI has the ability and strength in vegetation mapping and discrimination of water hyacinth from other vegetation types. A study conducted by Thamaga and Dube (2018) on understanding the seasonal dynamics of invasive water hyacinth in the great Lateba River system using Sentinel-2 MSI satellite data produced accurate results. Classification test result showed that seasonal water hyacinth distribution pattern can be accurately detected and mapped using Sentinel-2 with an overall accuracy of 80.79% during wet season and 79.04% during dry season. They recommended the need for continuous monitoring of aquatic species in small catchment areas using non-commercial sensors.

Verma et al. (2003) assessed changes in water hyacinth coverage of water bodies in northern part of Bangalore city Karnataka, India, using temporal remote sensing data. The study made use of Indian Remote Sensing Satellite (IRSS) LISS-II and III images of different years/seasons (1988–2001) to compare the water-covered and the water hyacinth-covered areas of six water bodies including Doddabommasandra, Yelahanka, Jakkur, Rachenahalli, Nagavara and Hebbal. Their findings showed that the area under water-hyacinth cover had increased in recent times compared with previous years. Recent developments in remote sensing data acquisition and processing tools presents more possibilities in terms of application in plant detection as compared to those used under Verma et al. (2003) and others. The remote sensing data used under this study was however of relatively coarse resolution as compared to IRSS (for 1988 -2001). Therefore, the information concerning reliable extent and pattern of water hyacinth distribution is required to determine its severity through time, relate its abundance to the environmental factors, and identify threatened water resources for provision of control measures as well as assessing their effectiveness (Thamaga & Dube, 2018).

2.3 Effect of water hyacinth on the physico-chemical water properties

2.3.1 Water quality

Water is the second most important need for life after air. It is essential resource on earth, providing numerous socio-economic and ecological benefits at household, farm and global scale such as recreational, fisheries, agricultural, industrial and domestic use (Forslund et al., 2009: Thamaga and Dube, 2018). As a result, water quality has been described extensively in the scientific literature. The most popular definition of water quality is “it is the physical, chemical, and biological characteristics of water” (Spellman, 2013). It is a measure of the condition of water relative to the requirements of one or more biotic species and/or to any human need or purpose. Each of the designated water uses has different defined chemical, physical and biological standards necessary to support that use (Karr

1991). Based on its source, water can be divided into ground and surface water (Balde et al., 2017). Both types of water can be exposed to contamination risks from agricultural, industrial, and domestic activities, which may include many types of pollutants such as heavy metals, pesticides, fertilizers, hazardous chemicals, and oils (Ritter et al., 2002)

Water quality can be classified into four types that is, potable water, palatable water, contaminated (polluted) water, and infected water (Omer & nayla, 2019: Bhattacharya et al., 2015). Potable water is safe to drink, pleasant to taste, and usable for domestic purposes. Palatable water is esthetically pleasing; it considers the presence of chemicals that do not cause a threat to human health. Contaminated (polluted) water is that water containing unwanted physical, chemical, biological, or radiological substances, and it is unfit for drinking or domestic use whilst infected water is contaminated with pathogenic organisms(Schweitzer et al.,2018). Water quality properties fall under the three major types of parameters that is physical, chemical, and biological (Karr et al., 1981). Common specific water quality parameters include turbidity, transparency temperature, Electrical conductivity pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Total phosphates and Chemical Oxygen Demand (COD) (Tchobanoglous, 1985; DeZuane, 1997; Shah, 2017).

Turbidity measures the cloudiness of water. It is a measure of the ability of light to pass through water. It is caused by suspended material such as clay, silt, organic material, plankton, and other particulate materials in water (Alley, 2017). Turbidity in water arises from the presence of very finely divided solids (which are not filterable by routine methods). Palatability, viscosity, solubility, odors, and chemical reactions are influenced by water temperature (APHA, 2005). Thereby, the sedimentation and chlorination processes and BOD are temperature dependent. It also affects the biosorption process of the dissolved heavy metals in water (Abbas et al., 2014). Most people find water at temperatures of 10–15°C most palatable. Water transparency is a key factor in lake water (water bodies) as the sun is source of energy for all biological phenomena. Transparency as a water quality parameter gives an indication of the presence or absence of suspended matter, living or inert, and hence it is a reflection of the overall quality of water. However, it must be remembered that the presence of any undesirable substances in solution will not be indicated by transparency. Transparency expressed as the maximum depth in meters at which it is possible to distinguish the markings of a Secchi disc, and it is widely used in studies on lakes to assess the abundance of algae. pH is one of the most important parameters of water quality. It is defined as the negative logarithm of the hydrogen ion concentration. It is a dimensionless number indicating the strength of an acidic or a basic solution. Actually, pH of water is a measure of how acidic/basic water is (White et al., 1997). Acidic water contains extra hydrogen ions (H+) and basic water contains extra hydroxyl (OH−) ions. Pollution can modify the pH of water, which can damage animals and plants that live in the water. For treated water, excessively high and low pH can be detrimental for the use of water. A high pH makes the taste bitter and decreases the effectiveness of the chlorine disinfection, thereby causing the need for additional chlorine (Spellman, 2017). The amount of oxygen in water increases as pH rises. Low-pH water will corrode or dissolve metals and other substances. Dissolved oxygen is considered to be one of the most important parameters of water quality in streams, rivers, and lakes. It is a key test of water pollution (APHA, 2015). The higher the concentration of dissolved oxygen, the better the water quality. Oxygen is slightly soluble in water and very sensitive to temperature. For example, the saturation concentration at 20°C is about 9 mg/L and at 0°C is 14.6 mg/L. The actual amount of dissolved oxygen varies depending on pressure, temperature, and salinity of the water. For treated portable water, dissolved oxygen has no direct effect on public health, but drinking water with very little or no oxygen tastes unpalatable to some people. Bacteria and other microorganisms use organic substances for food. As they metabolize organic material, they consume oxygen (APHA, 2015). Another important indicator of water quality is BOD. The organics are broken down into simpler compounds, such as CO_2 and H_2O, and the microbes use the energy released for growth and reproduction. When this process occurs in water, the oxygen consumed is the DO in the water. If oxygen is not continuously replaced by natural or artificial means in the water, the DO concentration will reduce as the microbes decompose the organic materials. This need for oxygen is called the biochemical oxygen demand (BOD). The more organic material there is in water, the higher the BOD used by the microbes will be. BOD is used as a measure of the power of sewage; strong sewage has a high BOD and weak sewage has low BOD (Spellman, 2017).

The quality of water is influenced by many factors including; water hyacinth infestation, sewerage effluent, sedimentation, runoff, decayed organic material toxic, hazardous substances, Oils, grease, litter and rubbish(Ritter et al.,2002). It is widely reported that water hyacinths are a biological pollution with significant impact on the quality of water, aquatic life and the ability to alter nutrient cycling. They have considerable implications to the subsequent water uses that is, agricultural and domestic purposes (Matongera et al., 2017). Industrial, farming, mining and forestry activities can also significantly affect the quality of Lakes. For example, farming can increase the concentration of nutrients and suspended sediments, industrial activities can increase concentration of metal and toxic chemicals, and suspended sediments leads to increased temperature (Chawira et al., 2013). Low dissolved oxygen can have a negative impact by making water unsuitable for established or potential uses. There are however, other various microbiological agents like bacteria, viruses and protozoa, which can cause water pollution and related water-borne disease.

The water quality in the Murchison Bay on Lake Victoria is affected by a complex mixture of processes and driving factors including pollution, river inflows, lake levels, wetland management and flora and fauna population (Moreno et al., 2009:Akurut et al.,2017). It is reported that the Inner Murchison Bay water quality deteriorated exponentially between 2001-2014, due to increased pollution (Haande et al., 2011; Akurut et al., 2016). For such reasons, the suitability as the drinking water supply source for Kampala, Mukono and Wakiso districts may not be sustainable in the near future.

2.3.2 Water hyacinth and water quality

Water bodies continue to endure water hyacinth invasion globally. Most of the fresh water resources are facing significant threats from the invasion from such aquatic weeds (Hestir et al., 2015; Palmer et al, 2015). Uncontrolled invasion of freshwater ecosystem by aquatic weeds has the potential of causing disturbances to biodiversity, nutrient cycling, aquatic life habitat and most importantly water quality deterioration and degradation (Hestir et al., 2015; Porter et al., 2013; Matongera et al., 2017).

Water hyacinth is regarded as a form of biological pollution and a major component of anthropogenic global change (Hestir et al., 2015; Porter et al., 2013; Matongera et al., 2017). Like traditional pollutants, the invasion of lakes, rivers and reservoirs by aquatic weeds is currently causing environmental and most importantly economic losses to agriculture, recreational water use and fisheries according to Sibanda et al., 2018). It is estimated that individual countries spend millions of dollars every year in aquatic weeds control and eradication programs, the world over. For instance, in United States of America alone, approximately above 150 million dollars is required for routine annual chemical and mechanical management of these invasive weeds (Hestir et al., 2008; Matongera et al., 2017).

Large water hyacinth mats prevent the transfer of oxygen from the air to the water surface, or decrease oxygen production by other plants and algae (Villamagna and Murphy, 2010). When the plant dies and sinks to the bottom, the decomposing biomass depletes oxygen content in the water body (EEA, 2012). Dissolved oxygen levels can reach dangerously low concentrations for fish that are sensitive to such changes. Furthermore, low dissolved oxygen conditions catalyze the release of phosphorus from the sediment, which in turn accelerates eutrophication and can lead to a subsequent increase in water hyacinth or algal blooms (Bicudo et al., 2007). Death and decay of water hyacinth vegetation in large masses deteriorates water quality and the quantity of potable water, and increases treatment costs for drinking water (Mironga et al., 2011; Ndimele et al., 2011; Patel, 2012). The increasing prices of drinking water in Kampala, Mukono and Wakiso is attributed to the increased costs of production from Ggaba water treatment plants.

Other documented effects of water hyacinth include; clogging of waterways, supporting organisms that are detrimental to human health among others. Many large hydropower schemes are also suffering with the effects of water hyacinth (Wondie et al., 2013; Villamagna & Murphy, 2010). For example, cleaning intake screens at the Own falls hydroelectric power plant at Jinja in Uganda were estimated at one million US dollar per year (Porter et al., 2013).

Floating mats of water hyacinth support organisms that are detrimental to human health. The ability of its mass of fibrous, free-floating roots and semi-submerged leaves and stems to decrease water currents increases breeding habitat for the malaria causing anopheles mosquito as evidenced in Lake Victoria (Minakawa et al., 2008). Mansonioides mosquitoes, the vectors of human lymphatic filariasis causing nematode Brugia, breed on this weed. Snails serving as vector for the parasite of Schistosomiasis (Bilharzia) reside in the tangled weed mat. Water hyacinth has also been implicated in harbouring the causative agent for cholera. For example, from 1994 to 2008, Nyanza Province in Kenya, which borders Lake Victoria accounted for a larger proportion of cholera cases than expected given its population size (38.7% of cholera cases versus 15.3% of national population). Yearly water hyacinth coverage on the Kenyan section of the lake was positively associated with the number of cholera cases reported in the Province (Feikin et al., 2010). At the local level, increased incidences of crocodile attacks have been attributed to the heavy infestation of the weed, which provides cover to the reptiles and poisonous snakes (Ndimele et al., 2011; Patel, 2012).

Water hyacinth often clogs waterways due to its rapid reproduction and propagation rate. The dense mats disrupt socio-economic and subsistence activities (ship and boat navigation, restricted access to water for recreation, fisheries, and tourism) if waterways are blocked or water pipes clogged (Ndimele et al., 2011; Patel, 2012). The floating mats may limit access to breeding, nursery and feeding grounds for some economically important fish species (Villamagna and Murphy, 2010). In Lake Victoria, fish catch rates on the Kenyan section decreased by 45% because water hyacinth mats blocked access to fishing grounds, delayed access to markets and increased costs (effort and materials) of fishing (Kateregga and Sterner, 2009). In the Wouri River Basin in Cameroon the livelihood of close to 900,000 inhabitants has been distorted; the entire Abo and Moundja Moussadi creeks have been rendered impassable by the weed leading to a complete halt in all the socio-economic activities with consequent rural exodus. The weed has made navigation and fishing an almost impossible task in Nigeria (Cho et al., 2012).

2.4 Determinants of water hyacinth extent and distribution

The main institutions, which were instrumental to the transfer of biota between continents before the 20th century is given by Kitunda (2006): “First, Christian missionaries, particularly Catholic missionaries, brought to Africa their long-standing tradition of collecting and carrying with them Exotic plants and growing them in mission stations that they established in foreign lands. Jesuits, Capuchin, and the White Fathers missionaries are said to have introduced water hyacinth in the offshore islands of Africa from the early 17th century onward. Around 1900 the White Fathers introduced water hyacinth in Rwanda, at the headwaters of the Kagera River, which drains into Lake Victoria and exits the lake as the Nile River (Parolin, Pia et al., 2010). The second factor in the spread of water hyacinth in Africa was a network of museums, which emerged in the 19th century. Early samples of water hyacinth are still available in museum herbaria in Africa. The plants escaped from these herbaria to the open water in the 20thcentury, but mere escape was not enough to allow the plant to proliferate. Another set of factors; change in hydrology and chemistry of African water Courses promoted the expansion of small amounts of water hyacinth to crisis levels (Parolin,Pia et al.,2010).

The third important institution in the transfer of water hyacinth to Africa and Asia was the network of botanic gardens and fish hatcheries that Europeans established in Africa from the middle of the 17th century. Subsequently, navigation activities between various European missionary or botanical stations promoted accidental spread of water hyacinth along the African watercourses (Xu et al., 2012; Akurut et al., 2014).

Various studies have indicated a sharp decline in the extent of water hyacinth on Lake Victoria, but it is clear that the Murchison Bay still has a large expanse of water hyacinth infestation (Haande et al., 2011; Akurut et al., 2014). It is reported that by 2012 the Bay had about (17.1 ha) of water hyacinth infestation (Haande et al, 2011). Hacky (1993) indicates that Lake Victoria is becoming more eutrophic and suggest that eutrophication may have been accelerated by the successful invasion of water hyacinth as it has a high nutrient requirement. Villamagna (2009) reviewed studies conducted on water hyacinth and found that the effects of water hyacinth on water quality worldwide varies with the extent of coverage and the spatial configuration of water hyacinth mats. Therefore, the 17.1 ha infestation of water hyacinth in the Murchison is likely to have a substantial impact on the quality of water in the Bay. Akurut et al. (2014) states that the rapid accumulation of water hyacinth biomass in Murchison Bay was facilitated by three main factors including well sheltered by a hilly shoreline and by several island; sewerage effluent and the influence of blowing of local winds usually not strong enough. This study investigated these factors too in relation to water hyacinth distribution in Murchison Bay.

Studies show that water hyacinth can grow well in temperature ranging between 25^0c and 27^0c (Gichuki et al., 2012). Experimental studies under controlled laboratory conditions have shown that the number of daughter plants is greatest at certain levels of temperature and relative humidity (day/night temperatures of $25^0/20^0$c to $40/25^0$c and relative humidity of 15/40% to 75/950%

(Bhattacharya et al., 2015). Growth stops if the water temperature falls below 10^0c or rises above 40^0c.

Another determining factor for the growth of water hyacinth is pH. This has to be between 6 and 8. When the value moves outside this interval, the plant can regulate pH of the medium within this range with its growth frequently resulting in the alkalization of the water maximum growth (number of plants and dry weight) is at pH 7, with pH 3.2-4.2 being very toxic on the plant, and 4.2-4.3 inhibitory and 4.3 – 4.5 possibly inhibitory (Téllez et al., 2008)

The speed of the current must also be taken into account. The floating form of the plant does not take roots so that it is exposed to the kinetic action of the water current. To be able to constitute a stable population, it requires the support of macrophytes on which to anchor. Since the currents facilitates the dispersal of propagules and stalons, and hence the colonization of new areas, it is a biotic factor of considerable importance for the potential propagation of the infestation in a given territory (Téllez et al., 2008)

Previous studies have shown that both the depth of the water and changes in lake water levels are important for the growth and expansion of water hyacinth. The reports suggest that the plants have more roots in deep waters than in shallow waters, while the leaf area and the summer growth of the plant are greater in shallow waters (Thamage and Dube, 2018). In Rivers infested with water hyacinth that are characterized by major fluctuations in the lake water levels, such as the Nile there has been some studies on the population and these ecological factors.

The species genetic makeup which is responsible for its reproductive strategy and capacity for the growth is also of great importance in contributing to the invasion (Bajwa & Ali, 2016). It is known that variations in the invasive potential of the water hyacinth reflect its preference for the new habitat and the availability of propagules (Tellez et al., 2008).

The water hyacinth is a plant that produces both vegetative and sexually, the former being the more important for the plant's rapid expansion and colonization through the formation of stalons. Reports indicate that water hyacinth has an extraordinary growth rate. This has been calculated to be an increase in biomass of 400-700 tons per ha day or an increase in water area coverage by factor 1.012-1.077 per day (Shanab et al., 2010; Villamagna & Murphy, 2010; Khanna et al., 2011).

2.5 Study gaps identified in the literature

Water quality studies that have been conducted in the Murchison Bay have mainly associated water quality deterioration in the Bay to industrial effluent and Nakivubo channel effluent discharge. The effect of water hyacinth on the physico-chemical water quality properties involving the use of GIS and relatively high-resolution remote sensing data was understudied, specifically detecting the spatial distribution and configuration using Sentinel-2 Images has never been applied in the Murchison Bay. With the help of remote sensing and GIS tools, essential information for proper mitigation and control of the waterweed can be acquired thus reduce contamination levels of the bay. There was therefore need for a comprehensive assessment of water hyacinth effects on the physico-chemical water quality properties in Murchison Bay.

CHAPTER THREE: METHODOLOGY

3.0 Introduction

This chapter presents the methods that were used to conduct the study. It covers a description of the research design, study population, sampling techniques, data collection and analysis.

3.1 Description of the study area

3.1.1 Location

The study area is within Murchison Bay along the shores of Lake Victoria, in Kampala district in Uganda (Figure 3.1). It is situated within coordinates, 458009.22 m E and 32850.08 m N, 457764.39 m E and 27035.51 m N, 464464.37 m E, and 26294.56 m N, and 464946.21 m E and 31880.19 m N. Murchison Bay is an extension of Lake Victoria located in the South-East of Kampala; which lies between latitude 000 10’000N -000 30’000’N and longitudes 320 35’00’E-32050, 00’’E with average elevation of 1224 m above sea level. Temperatures around the Bay ranges from 25 to 32^{o}C (Mubiru et al., 2012), winds are around 6.9 km/per hour north. Wind-induced mixing influenced temperature and water quality (Moreno et al., 2009).

The Murchison Bay covers an area of about 62 km^2 and can further be split into the Inner and the Outer Bay as their characteristics differ tremendously. The Inner Murchison Bay has an area of about 25 km^2 and an average depth of 3.2 meters. It is the abstraction point for portable water supply for Kampala. The Inner Murchison Bay is relatively shallow but deep at the pelagic area with convoluted shoreline, and narrow at the exit to the outer Murchison Bay. This helps in the mixing of the water between the Inner and the outer Bay. The inner Murchison Bay is comparatively a semi-enclosed small water body with an area of 25 km^2 and the length of 5.6 km off the main part of the lake. The

Murchison Bay has an average catchment area of 282 km^2 comprising of both wetland and urban areas of the city.

The depth of Murchison Bay in 2004 was 7meters, but by 2008, it had dropped by 1 ½ meters (Haande et al., 2011; Moreno et al., 2009). The major channels/wetlands that drain into the Murchison Bay includes; Nakivubo which drains Kitante, and Lugogo channels with inlets into the inner Murchison Bay, Kansanga wetland which stretches into the Ggaba shoreline, Kinawataka that drains industries of Nakawa and Kyambogo, and Namanve wetland (Sekabira et al., 2010).

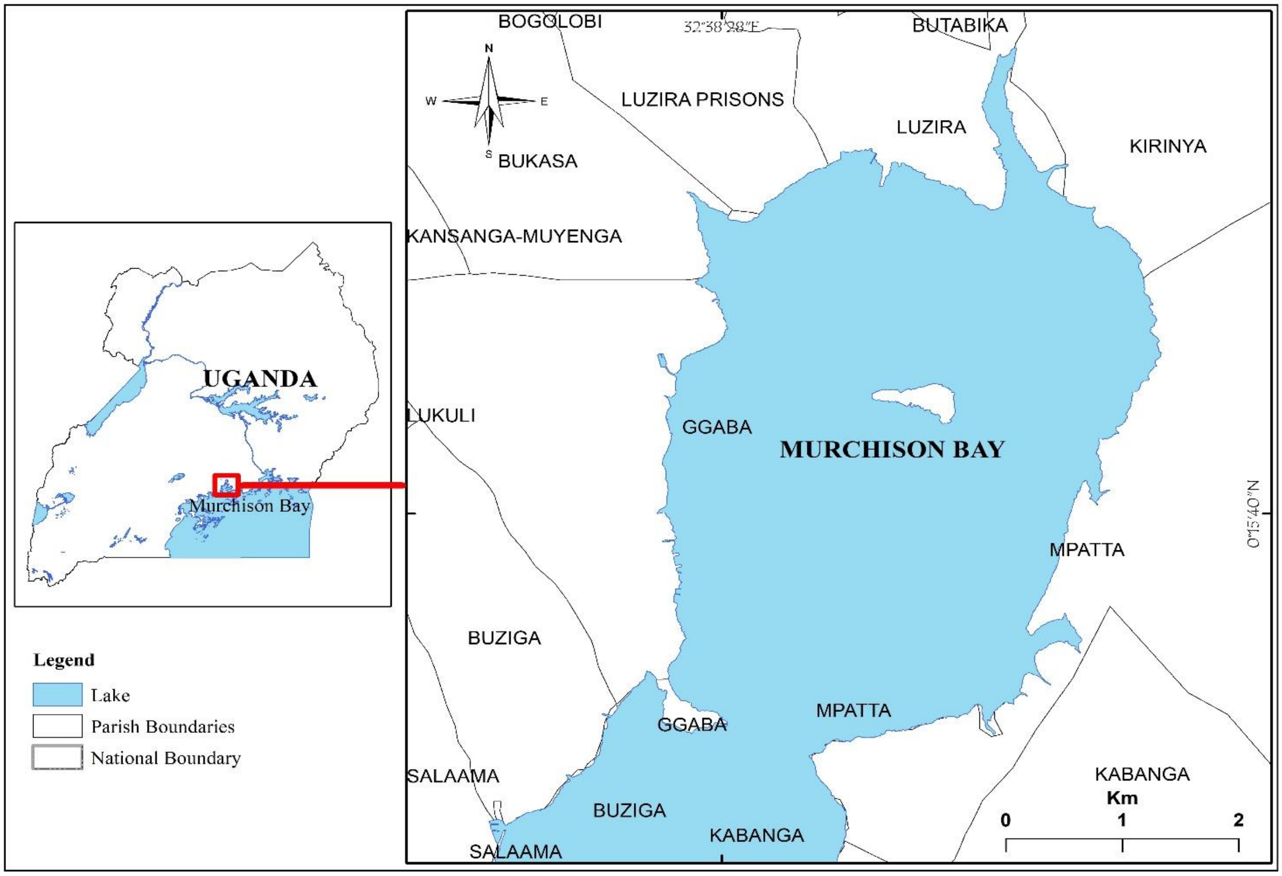

Figure 3.1: Location of the Study Area

3.1.2 Climate

The Murchison Bay is within the equatorial belt and experiences a moist sub-humid climate. It receives a bi-seasonal rainfall in the period of March to May and September to November. Mean monthly precipitation ranges from 24 mm in January to about 154mm in October with mean precipitation of about 1293 mm/year. The climate is tropical with small variations of humidity and winds throughout the year. This is attributed to high altitude and long distance from the sea. (Nsubuga et al., 2014). The Murchison Bay has warm temperature ranging from 23^{o}C to 32^{o}C. Temperature reaches the maximum in February, just before the March equinox and its lowest records in July after the June equinox (Mubiru et al., 2012).

3.1.3 Socio-Economic Activities

The main activities practiced in the area are; water production for both domestic and commercial uses from the inner Murchison Bay, industrialization, angling, boat fishing, craft making due to the presence of papyrus vegetation in the Bay, subsistence agriculture, recreational activities and navigation. The Bay has the main inland port for Uganda (Port Bell). The Murchison Bay is the main source of water for domestic, agricultural, industrial activities as well as the surrounding towns of Mukono, Wakiso and Bweyogerere. Although the Bay plays an important social economic role in the development of Kampala and surrounding towns, it has a history of serious pollution problems dating back in 1990s. The Bay has been invaded by water hyacinth.

3.2 Methods

3.2.1 Water hyacinth extent and distribution pattern mapping

3.2.1.1 Data sets used

High-resolution satellite images covering the Murchison Bay were acquired from Sentinel-2 series archive, manned by the United States Geological Survey (USGS) (http://glovis.usgs.gov/web-link). The images were for the period between 2016 and 2019 with tiles of Sentinel-2 MSI covering the study area. A single image was collected for each year and this had to be of the dry period (between January and March) during which there is less cloud cover to mask ground features. Images selected were those with less than 5% cloud cover as image analysis was to be based on mainly the visible bands (RGB & IR). Sentinel-2 images were preferred to Landsat 8 ETM due to the high spatial resolution (Sentinel with bands in 20*20 meters verses Landsat with 30*30 Landsat data). Since its launch in 2013, Sentinel data has become more and more applied in the mapping of land features thus serving as an alternative to coarse resolution Landsat series data (Sibanda et al., 2015).

3.2.1.2 Preprocessing

The Images were atmospherically corrected using Dark object subtraction (DOSI) model under semi-automated classification (SCP) embedded in Quantum GIS (QGIS) 3.12 software. The bands were converted into surface reflectance. QGIS software was preferred for use due to its advantage over other software. For example, it is an open-source software meaning there are no limitations to its access. It is also very fast compared to other software. QGIS is compatible with windows, Linux, android, mac OS, which makes it easier for user to install and use on their personal computers.

3.2.1.3 Processing

To determine the pattern and distribution of water hyacinth in Murchison Bay, the pre-processed Sentinel-2A images were further processed using maximum likelihood supervised classification algorithm in QGIS. The model distinguishes pixel properties for different land uses and cover (for which water hyacinth was part) basing on an input training data of pixels representing the predefined land use/cover classes (Table 3.1). Basing on this data, the algorithm portions the remaining rest or the pixels on an image basing on the training data. Maximum likelihood classification model was selected for classification satellite data in this study due to the high precision in land use and land cover classification as reported in previous studies (Sibanda et al., 2015; Matongera et al., 2017), (Shoko and Mutanga, 2017). Sentinel-2 data had never been applied in detection of water hyacinth in the Murchison Bay.

Table 3.1: The land cover/use types' classification system used for Murchison Bay area

Land cover/use class	**Description**
Built-up/settlements	Land consisting of residential areas slums and tenements and associated infrastructure
Burnt/bare earth	Areas with burnt vegetation and/ or exposed earth as a result of vegetation removal
Lake	Areas covered by lake water in the Bay
Forest	Areas under naturally existing tree cover
Water hyacinth	Areas covered by the water weed and host wetland vegetation with in the water body.

In addition, field data collection was conducted to record the location of water hyacinth using a GPS (primary data) during the months of November, and December 2019 and January and February 2020. These were randomly generated sampling points across the Murchison Bay but following water hyacinth infested areas (Appendix I). These points were used in a training data set for mapping the extent and pattern of water hyacinth.

3.2.1.4 Post processing

The post processing of the classified Sentinel-2 images involved computation of areal statistics for the cover classes for the images corresponding to the study period (2016 ~ 2019. Using discriminate analysis (DA), the various changes in coverage of the water hyacinth vis-à-vis, other covers in Murchison Bay were determined, which indicated the pattern and distribution of the water hyacinth in the Bay over the study period. The results were shown using tables and graphs. The QGS semi-automatic classification plug-in allows for calculation of several classification accuracy statistics such as overall accuracy, user’s accuracy, producer’s accuracy, and Kappa efficient (Semi-Automatic Classification Plugin Documentation, Release 5.3.2.1. 2017). The steps involved in image data acquisition, processing, and analysis are illustrated in Figure 3.2.

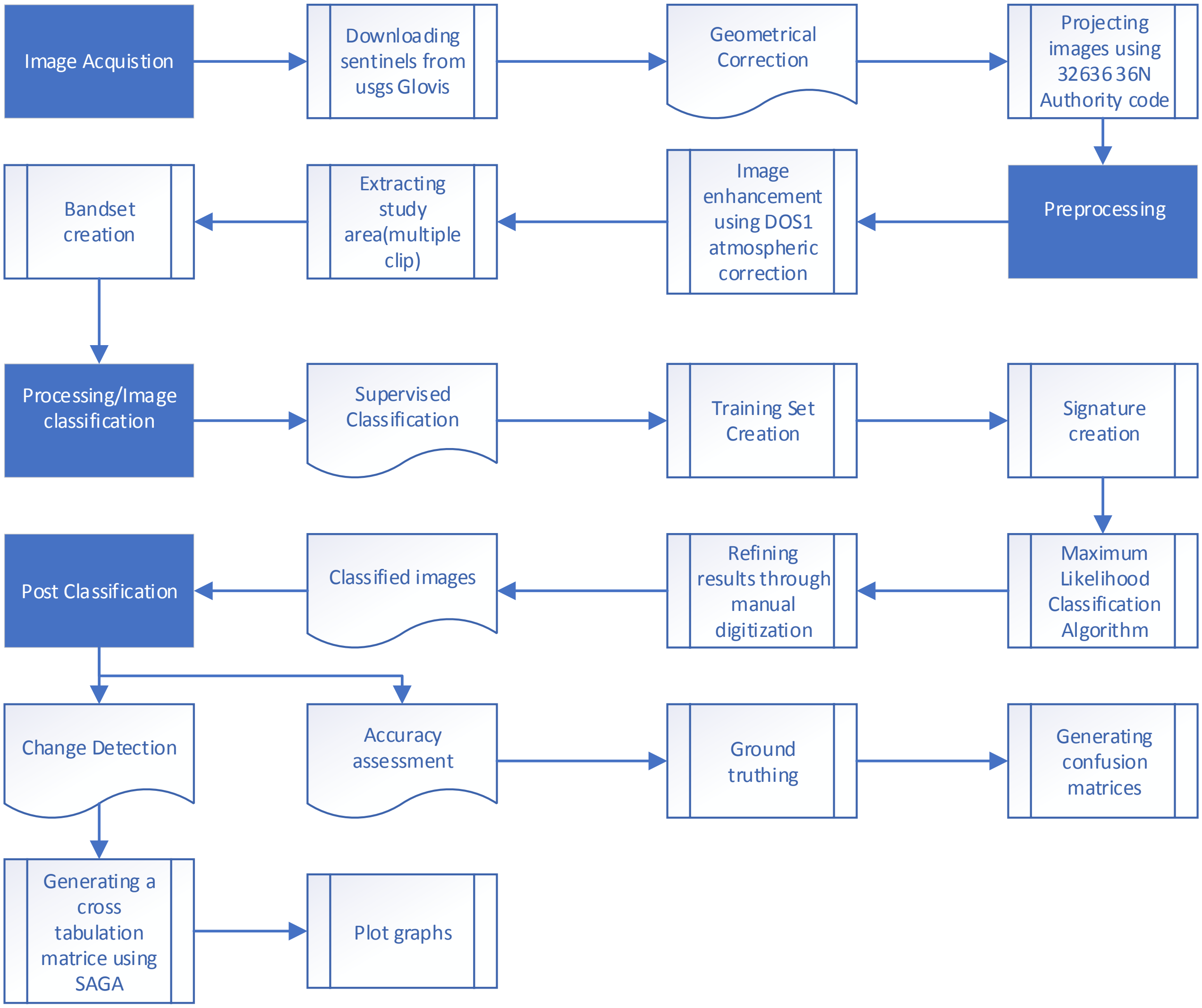

Figure 3.2: Methodological flow chart for water hyacinth mapping

3.2.2 Determining the effects of water hyacinth on the physico-chemical water quality properties

3.2.2.1 Water sampling

Water samples were drawn using 1000 ml water sample collector and poured in 500 ml plastic water sample bottles which were stored in boxes before transferring them to the laboratory (NWSC Labs at Ggaba and Lubigi) for specific water quality parameters of interest to this study. The bottles were washed with nitric acid to remove any form of contaminants and to ensure that the physical properties of water samples are maintained. The parameters of interest included pH, Water Temperature, Total Phosphate (TP), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Electrical Conductivity (EC), Chemical Oxygen Demand (COD), Turbidity and Transparency. These were selected specifically because they are key indicators of overall water quality and thus impact on human health, water production, and ecosystem health (Tchobanoglous, 1985; DeZuane, 1997; Shah, 2017). Water Samples were picked from two environments within the Bay, that is, under stationary floating water hyacinth, and under water hyacinth free (open water environment). 10 sampling points were selected from each of the environments and three samples at each sampling point in relation to water depth (near water surface, middle and bottom) (Figure 3.3).

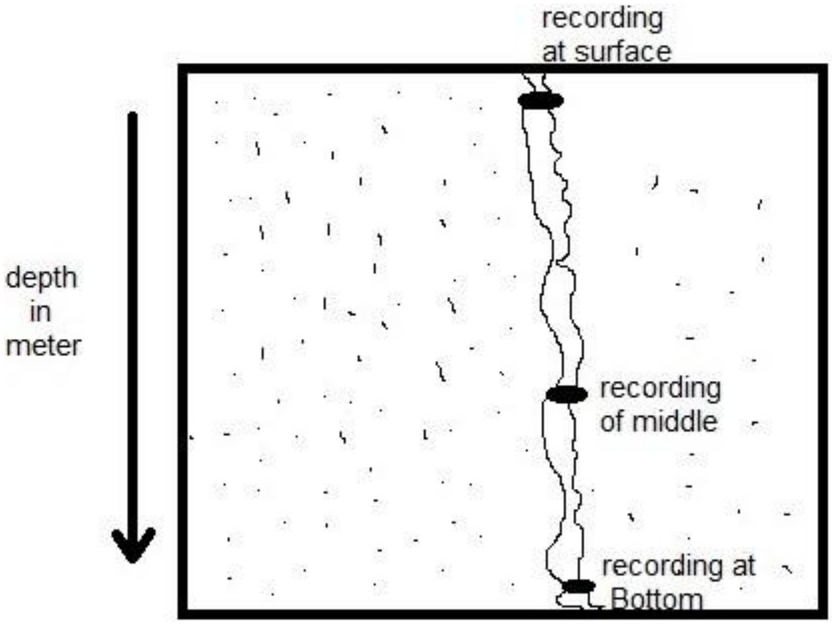

Figure 3.3: Sampling depth interval at each collection point

The sampling locations were accessed using a motorized boat and at each sampling point, GPS coordinates were recorded. Whereas sampling in the open-water environment was done randomly, that under the water hyacinth environment was done purposely and systematically (following a mean distance interval of 500 meters. All water samples were collected from the inner Murchison Bay (Figure 3.4). Two different sampling occasions were conducted. The first sampling activity was conducted between September and December. This period represented samples for the wet period. The second sampling activity was conducted between January and February (2020). This period represented sampling for the dry season. Thus, a combination of data from two different seasons accounted for any variations in water quality brought about by seasons (November/December 2019 and January/February 2020).

Figure 3.4: Water collection during the field study (field photographs-November, 2019)

Some water parameters such as DO, temperature and transparency were measured and tested in the field, while others like Turbidity, pH, TP, EC BOD,and COD were tested in the laboratory using set standard procedures (APHA, 2005) (Figure 3.5). Temperature and DO were measured using dissolved oxygen meter. The DO meter was immersed in the collected water sample, and the results for both parameters are displayed on the DO meter. Temperature was then recorded in degrees, and DO was also recorded. Transparency on the other hand was measured using a secchi disk. The disc was dipped into the water at every sampling point and the depth at which the disc is no longer visible was recorded in meters.

Figure 3.5: Laboratory water quality data analysis at NWSC labs in Ggaba

Water pH and E.C were measured by electrometry method with the help of pH/EC multimeter (Hach Sension +MM374). This device has two probes, one for measuring pH and the second for measuring conductivity. 100 ml of the sample was poured into a 100ml beaker and the probes were lowered into the sample before starting the machine. The sample was stirred by help of a magnetic stirrer until a stable reading was obtained and displayed on the equipment display screen. The machine displays both the pH and EC (µs/cm) values, which was recorded. pH has no units while EC was measured in Siemens per meter (S/m).

Turbidity of the water samples was determined by the use of a turbid-meter (Hach TL 2300). The sample was uniformly mixed and poured into a 40 ml cell up to the mark and then inserted into the machine to read off its turbidity. The machine displayed the turbidity value in nephelometric turbidity units (NTU) on the display screen.

Chemical Oxygen Demand (COD) determines the amount of oxygen required for oxidation of organic matter using a strong chemical oxidant such as potassium dichromate under reflux conditions. The test is widely used to determine the same types of pollution as the BOD expressed in milligrams per liter (mg/L). COD was determined by oxidation of organic matter using acid dichromate solution followed by spectrophotometric determination. The digestion tube and caps were washed with 4ml H_2SO_4 to prevent contamination .2 ml of sample was poured in the digestion tube ,followed by adding 2.0 ml of potassium dichromate digestion solution.

The above process allowed an acid layer to be formed under the sample digestion layer

Cap tubes were swirled several times to mix completely, without inverting the tubes.

The solution was placed in a preheated oven of 150^0c for 2 hrs.

This was followed by reading the concentration of the sample with the help of spectrophotometer DR 6000.

BOD is a measure of the amount of oxygen consumed through biochemical degradation of organic carbon, inorganic materials and nitrogenous compounds present in waste water over a specified incubation period usually 5 or 7 days. It was determined using the procedure below:

- Preparation of dilution water by transferring a desired volume of water into a bottle, and then saturating the water sample with dissolved oxygen (DO) by aerating with organic free filtered air. Adding 1 ml of each of phosphate buffer, $MgSO_4$, $CaCl_2$ and $FeCl_3$ solutions /l of saturated water, and Mixing thoroughly before starting to use.
- Preparation and measurement of initial DO by adding specific volume of the sample to the individual BOD bottles of known volume. Filling the bottles up to the brim with sufficient

dilution water. Reading DO1 using the dissolved oxygen meter (Hach), then taking the initial reading. Tightly sealing the bottle leaving no air bubble and incubating for 5 days at 20°C. After 5-day incubation, residual DO was determined in the samples. BOD was eventually determined using the formula;

$$\text{BOD, mg/l} = \frac{(D1 - D2)}{P} * 300$$

Where,

D1 = DO of dilute samples immediately after preparation, mg/l

D2 = DO of diluted water after incubation at 20°C, mg/l

P = decimal volumetric fraction of sample used

300= Volume of the BOD bottle used

To determine **TP** (in (mg/L), organically combined phosphorus and all phosphates were converted to orthophosphate. To release the phosphorus as ortho–phosphate from organic matter, wet oxidation technique was applied. This was based on wet oxidation with potassium per-sulphate. The same procedure for orthophosphate determination was followed. The procedure involved:

- Taking 25ml diluted or whole sample, acidifying with 1ml H_2SO_4, 0.04 M, adding 5ml digestion reagent, mixing thoroughly.
- Preparing blank (25ml distilled water) and phosphate standard by taking 25ml of known standard concentration. Treating both blank and phosphate standard in the same way as sample.
- Heating for 30 minutes in an autoclave at 120°C and cooling at room temperature.

- Colour reaction is made in destruction bottles. Adding 3ml combined reagent comprising (50 ml of 5N H_2SO_4 +5ml potassium antimonyl tartrate +15ml ammonium molybdate only), mixing thoroughly.
- Finally adding 1ml of ascorbic acid to each sample. Swirl to mix.
- Allowing to stand for 20 minutes for blue colour development (it remains stable up to 2 hours).
- Measuring the concentration in mg/L at 880 nm wavelength using the spectrophotometer DR 6000 and multiplying the reading by the dilution factor; and
- Recording the results straight in the workbook.

3.2.2.2 Data Analysis

Data on water physico-chemical properties obtained using both field and laboratory methods (appendix III) were largely numeric and thus analysis-involved use of parametric statistical techniques. This data was organized into tables in Microsoft excel (2016) sheet. The file was then imported into R statistical computing software. Using this program, first, exploratory and descriptive statistics were computed including maximum, minimum, 1st Quartile, Median, 3rd Quartile, Mean, Variance and Standard deviation for each of the physico-chemical water quality properties. These were computed for the two data sets representing water hyacinth and non-water hyacinth environments and the analysis was meant to summarize the data and give a snap shot of the emerging differences and similarities in the values of water quality parameters for the samples from the two sampling environments. At the second phase, data on the water quality parameters was subjected to a Two-way Analysis of Variance (ANOVA). That is, type III Sums of squares were computed on each of the water quality variables' data in relation to the sampling environment and sampling depth. Both the sampling environment and sampling depth were treated as categorical whilst water quality was measured on a continuous scale. This analysis was meant to show both the independent and interactive effect of water hyacinth and water depth on water quality parameters based on the level of significant of these factors' influence on water quality as indicated by their P-values. The ANOVA model was considered appropriate because the two sampling environments and water sampling depth as independent variables were treated as categorical variables verses the continuous dependent variable (water quality parameters) (Sture, 2016; Eleisa, 2009; Shaw, Mitchell-olds, & Sep 2007). Equation 1 below gives the ANOVA model used.

$$y_{ij} = \mu_i + \varepsilon_{ij} ,$$

where $j = 1, \ldots, n_i$ and $i = 1, 2, 3$

y_{ij} is the j^{th} water quality parameter values of the i^{th} level,

$E(y_{ij}) = \mu_i$, $\varepsilon_{ij}'s$ are the random error term which are assumed to be independent and normally distributed that's $\varepsilon_{ij} \sim N(0, \sigma^2)$.

The estimated mean physico-chemical water quality values of each category were used in the comparison to represent the i^{th} categories defined based on the sampling environment and depth. Based on this model, two hypotheses were tested namely;

1- There is no significant difference in the quality of water between water hyacinth and open lake environments.

2- Water physico-chemical properties are the same at different lake depths.

3.2.3 Perceived determinants of water hyacinth pattern and distribution in Murchison Bay

3.2.3.1 Household Survey

3.2.3.2 Research Design

Across-sectional research design was adopted to study the pattern and extent of water hyacinth distribution, effect of water hyacinth on physico-chemical water quality properties and establish determinants of water hyacinth extent and pattern in the Murchison Bay as perceived by the residents. The study design was implemented following both qualitative and quantitative approaches. The quantitative approach was involved in the data obtained by questionnaires from respondents, specifically fishermen from Luzira, Mulungu and Ggaba landing sites, traders from Ggaba, Mulungu and Luzira markets, Fisheries department officials from Luzira Mulungu and Ggaba, and officials from National water and Sewerage Corporation.

3.2.3.3 Sample population and size

A sample is a part of the targeted population that is carefully selected in such a way that small portion represent a whole. For water hyacinth mapping, Sentinel-2 images covering Murchison Bay stretching from 2016 to 2019 were obtained and analyzed. For determinants of water hyacinth extent and pattern, officials from, fisheries department, NWSC, Traders, fishermen, especially those who are stationed at Port Bell, Ggaba and Mulungu landing sites were targeted and interviewed. These provided useful information concerning the extent and pattern of water hyacinth in the Murchison Bay. A sample size of 201 respondents from the above-mentioned categories was drawn. For water quality analysis, 10 pairs of sampling points locations were determined corresponding to the two environments that is water hyacinth infested and water hyacinth-free areas within Murchison Bay. From each sampling location, three samples were drawn that is, at near water surface, middle and bottom water depths.

The sampling points had to be located at an average distance of 500 meter from one another. Sampling point to another.

3.2.3.4 Sampling Techniques

Purposive sampling was used to select 201 respondents including the Fisheries department officials, fishermen, Traders and National water and Sewerage Corporation. These were selected on the criterion that they are involved in water resources and directly affected by water hyacinths. They were also considered more knowledgeable about the problematic waterweed (water hyacinth) in their areas of jurisdiction. A stratified sampling technique was also employed to select respondents from three landing sites around Murchison Bay. This involved division of the population into subgroups, and a two-stage sampling applied. A sample of 201 respondents were selected from the landing sites of Port Bell, Ggaba and Mulungu. 16 respondents were selected from the Fisheries departments of Ggaba, Mulungu and Luzira landing sites respectively. 120 respondents were randomly selected from the three landing sites, and 13 respondents from National Water and Sewerage Co-operation and the rest from the landing sites of Mulungu, Ggaba and Port bell. The data was collected between September and December 2019.

3.2.3.5 Data Collection

To gather people's opinions on determinants of water hyacinth pattern and distribution in Murchison Bay on Lake Victoria, questionnaires were distributed to 201 respondents selected from the landing sites of Ggaba, Mulungu and Port Bell. This data was collected using semi-structured questionnaires. The first section of the questionnaire captured respondents' background characteristics in terms of gender, age, occupation and length of stay or employment around the Bay. The second part collected data on water hyacinth characteristics in terms of time and areal extent of first and current invasion.

The third section collected respondents’ opinions in form of ranking the physical and human factors responsible for water hyacinth pattern and distribution in Murchison Bay over the years (Appendix II). The methodology was largely quantitative in nature involving gathering of people’s opinions, attitudes and feelings, and then coding the obtained responses into numeric data. This data came from Fisheries department officials, Fishermen, and officials from National water Sewerage Corporation, residents and businesspersons around Murchison Bay.

3.2.3.6 Data Analysis

Data obtained using questionnaires and structured interviews were computer coded with the help of SPSS software Version 23.0. Descriptive statistics and inferential analysis were applied on the data obtained by way of questionnaire in this study that is, the perceptions of people on the determinants of the extent and pattern of water hyacinth in the Murchison Bay. Data on respondents’ and water hyacinth problem’ background was analyzed inform of percentages and frequencies. The main section of the questionnaire required respondents to rank the factors that they think influence water hyacinth pattern and distribution in Murchison Bay. The respondents were asked to rate 15 factors on a scale of 1 - 4 to show the extent to which they believe a factor determines water hyacinth extent and pattern of distribution in Murchison Bay (where 1 indicates the least level and 4 indicates highest level of determination) and thus numeric data were generated. This data was summarized using descriptive statistics in form of mean, and standard deviation and presented in tables. To establish whether the perception remains the same across the three landing sites Pearson’s Chi square analysis was performed and the relationships were tested at alpha level 0.05. This yielded inferential statistics in form of Pearson’s Chi-square, likelihood and p-values, which were presented in tables.

CHAPTER FOUR: RESULTS

4.1 Mapping the extent and distribution pattern of water hyacinth in Murchison Bay between 2016 and 2019

Figures 4.1 indicates that water hyacinth concentrated mainly on the northern edges of the Bay as compared to the western and eastern edges over the reference study period. However, western and eastern edges of the Bay registered more concentration of the water hyacinth after the north in the years 2016 and 2018 as compared to 2017 and 2019. The land cover statistics reveal the overall variations of the water hyacinth over the four-year period (2016-2019) in the Bay as shown in Table 4.1. When the areal extent statistics of the various covers land covers were computed (Table 4.1), it was discovered that, water hyacinth in 2016 covered about 509,547 km^2 (1%) which, increased to 2434.353 km^2 (representing 4%) in 2017. The coverage dropped to 1,542.33 km^2, which was approximately 3% of the total coverage in 2018. Water hyacinth spatial extent however increased again in 2019 to 2138.43 km^2; representing 4% of the total areal coverage. The land cover/use changes between 2016 and 2019 are further illustrated in Figure 4.2. These results indicate that coverage and distribution of water hyacinth in Murchison Bay was neither even nor static in Murchison Bay within the studied period. That is, it varied over space and time (Table 4.1 and Figures 4.1 and 4.2). Although water hyacinth covered the smallest area (less than 5 %) over the years compared to other land cover types, its variability over space and time makes it difficult to manage. It means the distribution and coverage of the water hyacinth is impossible to predict due to its non-sedentary nature. The results also indicate that water hyacinth coverage largely increased with decrease in water surface area, which means that water hyacinth reduces on exposed water surface for other environmental processes like atmospheric water transfer.

Using remote sensing and GIS techniques, the areal extent of water hyacinth coverage for the period between 2016 and 2019 were mapped and the results are presented in form of raster maps (Figure 4.1.)

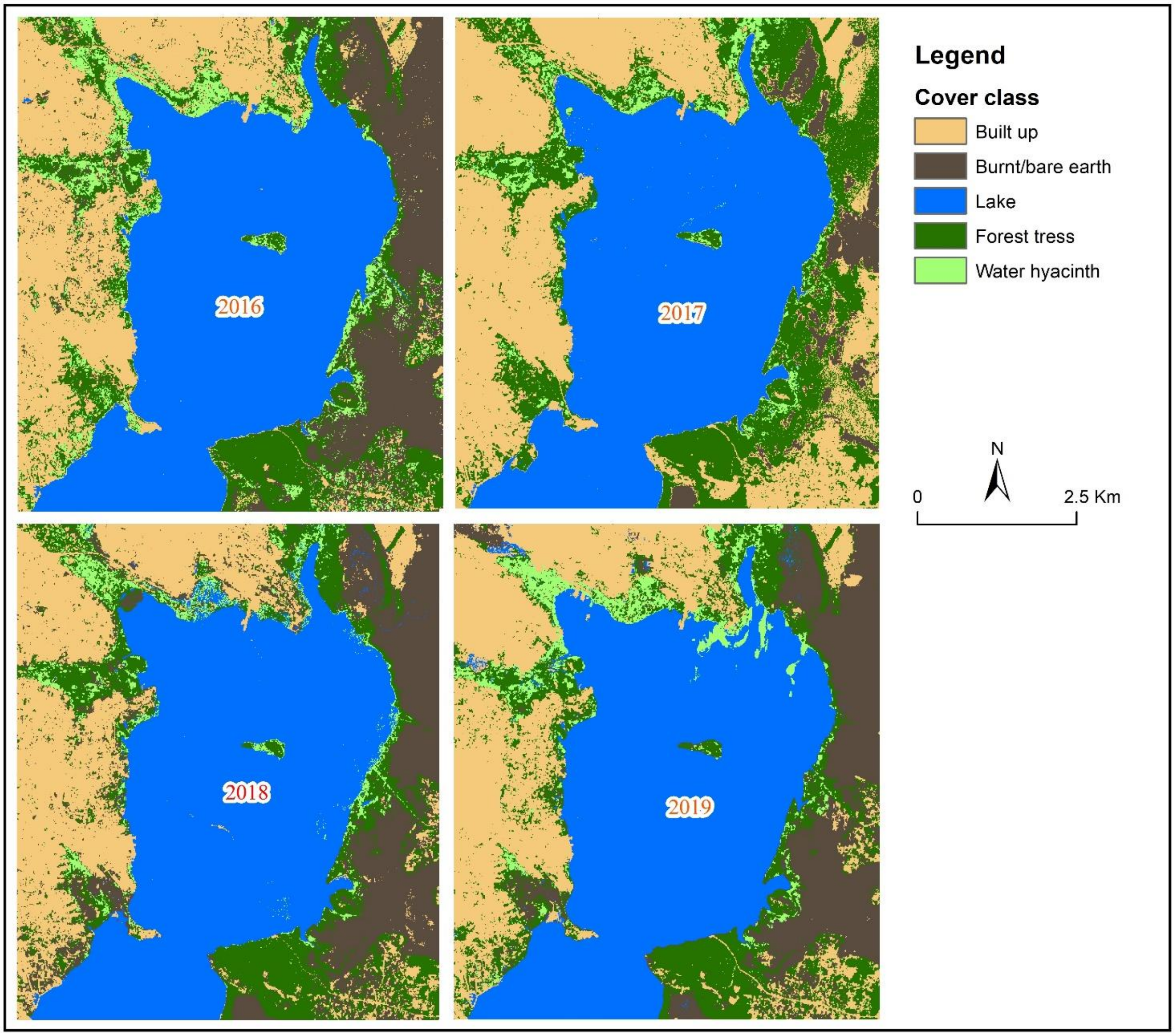

Figure 4.1: Water hyacinth cover in Murchison Bay between 2016 and 2020

Table 4.1: Area statistics of land cover around Murchison Bay between 2016 and 2019

Year	Built-up (km^2)	%	Burnt/bare earth (km^2)	%	Water (km^2)	%	Forest/trees (km^2)	%	Water Hyacinth (km^2)	%
2016	12006	24	8746	18	21414	42	7287	15	511	1
2017	13058	25	7108	14	21985	42	7663	15	2434	4
2018	12025	23	9461	18	21807	42	7414	14	1542	3
2019	12715	24	8282	16	21517	41	7596	15	2138	4

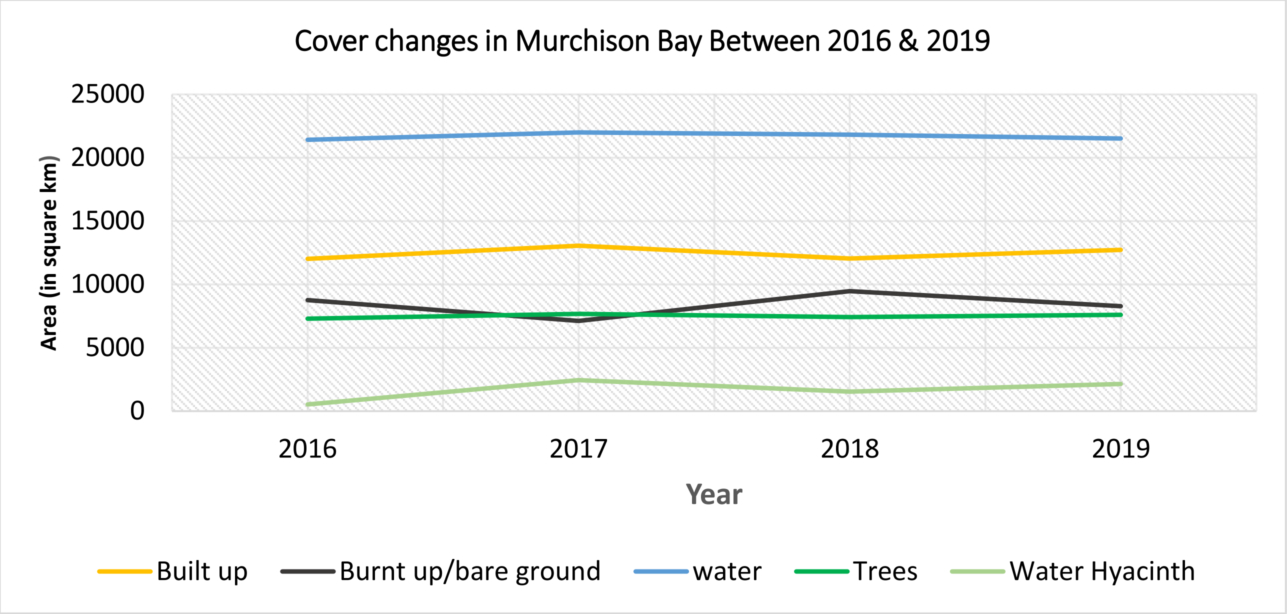

Figure 4.2: Land cover changes in Murchison Bay between 2016 and 2019

In terms of pattern of distribution, Figure 4.1 reveals that water hyacinth in Murchison Bay assumed a clustered pattern of distribution in the years 2016 and 2018 while in 2017 and 2019; the pattern of distribution largely took a dispersed structure. These patterns of water hyacinth distribution seem to reflect the movement of waves in the Bay, which are a reflection of wind direction. The patterns also reflect shoreline indentation such that shielded areas (micro Bays) within the large Murchison Bay tend to have a large concentration of the water hyacinth and these are mainly on the northern and north western parts of the Bay (Figure 4.3).

Figure 4.3: Distribution of the water hyacinth in Murchison Bay (field photographs-November, 2019)

4.1.2 Land use/cover change detection analysis between 2016 and 2019

Change detection results (Table 4.2) indicate that major land cover types' transitions occurred between lake and water hyacinth classes, which means that part of the water body become colonized by water hyacinth. On the other hand, major land use transitions occurred between built-up and burnt–up areas thus land-use accounted for some losses in vegetation cover in the study area.

Table 4.2: Change detection

Use/Cover	Built-up	Burnt/bare earth	Lake	Forest trees	Water hyacinth
Built-up	17	9.9	0.08	1.91	0.37
Burnt/bare earth	8.7	4.6	0.14	1.4	0.04
Lake	0.71	0.00	1.3	0.5	3.06
Forest trees	0.03	0.8	0.2	0.3	0.42
Water hyacinth	0.12	0.01	2.12	2.3	16.2

4.1.3 Classification Accuracy Assessment for the land use/cover changes between 2016 and 2019

The results from the classification accuracy assessment (Table 4.3) reveal an overall accuracy of 67% for the year 2019, 68.5% for 2018, 70% for 2017, 73% although individual accuracies for classes; built-up, lake, forest trees, water and water hyacinths depicted variations in user and producer accuracy values, thus minimal errors of commission and omission. The Kappa co-efficient was 61.5% for 2019, 60.5% for 2018, 62.5% for 2017 and 66% for 2016. These show that the classification accuracy was moderate and above average for the four years.

Table 2.3: Classification Accuracy Assessment for 2016 and 2019

2016

Use/Cover	Built-up	Burnt/bare earth	Lake	Forest trees	Water hyacinth	Sum	User's Accuracy
Built-up	17	5	0	2	0	21	66.7
Burnt/bare earth	5	15	0	1	0	22	72.7
Lake	0	2	9	0	4	15	88.2
Forest trees	0	0	0	13	4	17	76.5
Water hyacinth	0	0	3	2	13	17	70.6
Sum	22	22	12	18	21	92	
Producer' Accuracy	73.7	72.7	80	72.22	66.7		
Overall Accuracy	72.8						
Kappa	65.9						

2017

Use/Cover	Built-up	Burnt/bare earth	Lake	Forest trees	Water hyacinth	Sum	User's Accuracy
Built-up	12	5	0	2	0	19	63.2
Burnt/bare earth	5	10	0	1	0	16	62.5
Lake	0	0	12	2	5	19	88
Forest trees	0	0	0	16	3	19	84.2
Water hyacinth	0	0	2	2	13	17	76.5
Sum	17	15	14	23	21	90	
Producer' Accuracy	70.6	66.7	85.7	69.6	61.9		
Overall Accuracy	70						
Kappa	62.5						

2018

Use/Cover	Built-up	Burnt/bare earth	Lake	Forest trees	Water hyacinth	Sum	User's Accuracy
Built-up	14	2	2	1	0	19	73.7
Burnt/bare earth	5	12	0	1	0	18	66.7
Lake	0	2	9	0	5	16	56.3
Forest trees	0	1	0	15	3	19	78.9
Water hyacinth	0	0	3	4	13	20	65
Sum	19	17	14	21	21	92	
Producer' Accuracy	73.7	70.56	64.3	71.42	61.9		
Overall Accuracy	68.5						1710
Kappa	60.5						

2019							
Use/Cover	**Built-up**	**Burnt/bare earth**	**Lake**	**Forest trees**	**Water hyacinth**	**Sum**	**User's Accuracy**
Built-up	17	5	0	2	0	24	70.8
Burnt/bare earth	5	15	0	1	0	21	71.4
Lake	0	2	9	0	4	15	88.2
Forest trees	0	0	0	13	4	17	76.5
Water hyacinth	0	0	3	2	13	18	72.2
Sum	22	22	12	18	21	100	
Producer' Accuracy	77.3	68.2	75	72.2	61.90		
Overall Accuracy	67						
Kappa	61.5						

4.2 Effect of water hyacinth on physico-chemical water quality properties in Murchison Bay

4.2.1 Descriptive and exploratory statistics for water-quality parameters

Table 4.4 indicates that the highest maximum (10.8) pH values were registered under open lake environment while the lowest minimum (5.5) pH values were recorded under water hyacinth sampling environment. The mean pH for samples drawn from open lake environments was also higher than that of samples from water hyacinth environments. The trend is the same for the other statistics too. These results imply that PH as a water physico-chemical property decreases with increase in water hyacinth proliferation. Thus, water hyacinth affects water quality by reducing on its alkalinity and increasing on its acidity. Acidity might be released by the weed or conditions initiated by its presence. However, average pH values (6.7) for water under water hyacinth environment are close to the neutral value of (7) which is considered pure water fit for human consumption. This could be explained by the fact that open water environment allows for maximum circulation of water properties that leads to an increase in salinity.

The electrical conductivity (EC) values between the two sampling environments were not so different according to the statistics shown in Table 4.4 especially in terms of mean, median, and standard deviation. However, a high maximum (408) was registered under open lake environment. A slightly higher mean EC (146.8) under water hyacinth environment means that water hyacinth increases water electrical conductivity. This could mean that weed increases on the sold properties in water that act as electrical conductors and thus serve good electrical conductors.

The statistics in Table 4.4 further reveal that turbidity values for water samples picked from water hyacinth environments differed from those picked under open lake environments. That is, higher maximum (544), mean (66.3), median (59.6) for example were registered for turbidity under water hyacinth environments as compared to open lake environments. These results imply that water hyacinth affects water quality by increasing on its turbidity.

Statistics for COD reveal minor difference between water hyacinth and non-water hyacinth environments. The greatest differences are in the maximum quartiles and standard deviations. However, a critical look at the statistics for the two sampling environments shows that chemical oxygen demand values in terms of mean was higher (77.2) under water hyacinth environment with a slightly lower comparable standard deviation (29.4). The implication of the results is that water hyacinth affects water quality by increasing the chemical oxygen demand of the water while open water environments exert a lower chemical oxygen demand on the water body.

Table 4.4 further reveals higher total phosphate values in all statistics for water samples collected from water hyacinth environment except for minimum. The implication of these results is that water hyacinth impacts on water quality by increasing on the amount of phosphates in the water. This means that either water hyacinth plant produces properties of phosphorous material or it helps in attracting and trapping phosphates within the lake but from other sources. Thus, phosphates concentration in water increases with increased water hyacinth proliferation.

The statistics in Table 4.4 further reveal that BOD values for water samples picked from water hyacinth environments differed from those picked under open lake environments. That is, higher maximum (48) and mean (32.9) with a standard deviation of (7.3) for example were registered for BOD under water hyacinth environments as compared to open lake environments (maximum = 30, mean =21.8, standard deviation = 6.2). These results imply that water hyacinth affects water quality by increasing on its Biochemical Oxygen Demand.

Table 4.4: Descriptive and exploratory statistics for water-quality parameters between water hyacinth and open lake environments

Water hyacinth environment Statistics	pH	EC (S/m)	Turbidity (NTU)	COD (mg/L)	TP (mg/L)	BOD (mg/L)	Temp (^{O}C)	DO (mg/L)	Transparency (meters)
No. of observations	120	120	120	120	120	120	120	120	120
Minimum	5.5	102.1	6.05	16.0	0.2	17	24.1	5.3	0.1
Maximum	7.6	313	544	155	8.3	48	42	9	1
1st Quartile	6.2	122	54.4	56	2.5	28	25	6.5	0.25
Median	6.7	132.9	59.6	70	3.23	35	25.4	7.0	0.4
3rd Quartile	7.1	160.2	63.3	96.8	3.3	38.1	26.3	7.4	0.5
Mean	6.7	146.8	66.3	77.2	3.7	32.85	27	6.9	0.43
Variance	0.30	1870.8	3643.3	867	1.6	54.0	20	0.5	0.1
Standard deviation (n-1)	0.6	43.3	60.4	29.4	1.2	7.3	4.5	0.7	0.3

Open lake environment Statistics	pH	EC (S/m)	Turbidity (NTU)	COD (mg/L)	TP (mg/L)	BOD (mg/L)	Temp (^{O}C)	DO (mg/L)	Transparency (meters)
Minimum	7.3	99.7	29.1	17	0.1	3.0	0.10	6.7	0.1
Maximum	10.8	408	59	211	4.1	30	41	10.9	1.1
1st Quartile	7.9	125.2	45.6	51	1.1	19.2	24.7	8.0	0.4
Median	8.4	132.3	48.3	55.5	1.4	23.2	25.2	8.5	0.6
3rd Quartile	8.7	153.3	52.8	63.8	1.8	25.7	26	9.2	0.9
Mean	8.5	142.3	48.1	62.9	1.4	21.8	25.7	8.6	0.6
Variance	0.6	1752.5	38.2	909.2	0.6	39	26.6	0.9	0.1
Standard deviation (n-1)	0.8	41.9	6.2	30.2	0.8	6.2	5.2	0.9	0.3

Results on water temperature between water hyacinth and open lake environments did not differ much as shown by the statistics in Table 4.5. The emerging key difference are in terms of minimum and mean statistics. Water hyacinth samples returned a slightly high temperature mean (27) compared to open lake samples. This could imply that water hyacinth increases the temperature of the water although by a very small margin. This can be explained by the fact that water heat capacity is high as compared to open lake environment.

Another water quality parameter investigated between water hyacinth and open lake environments was dissolved oxygen, and the statistics summarized in Table 4.4 indicate that DO values were lower for water samples from water hyacinth environment compared to those from open lake environments. That is in terms of Minimum (5.3), Maximum (9), 1st Quartile (6.5), Median (7.0), 3rd Quartile (7.4), and Mean (6.9). The significance of these results is that water hyacinth decreases the amount of dissolved oxygen in water whilst open lake environment water is well oxygenated in terms of amount of dissolved oxygen.

Table 4.5 further reveals lower values for transparency of water in water hyacinth environment as compared to that from open lake sampling environment. The results mean that water under water hyacinth environments is less transparent as compared to that under open lake environments. Therefore, water hyacinth reduces the transparency of water as it increases on the number of suspended particles, which also increases turbidity.

4.2.2 ANOVA results

Data on physico-chemical water properties as measures of water quality were subjected to a two-way Analysis of Variance in relation to sampling environment (water hyacinth and open lake) and depth (near lake surface, mid, and lake bottom). Each of the water physico-chemical properties served as dependent variable, whereas Environment and Depth were considered key factors to have effect on water quality. The interactive effects of these two on water quality were also determined (Table 4.5)

Table 4.5: Analysis of Variance for Physico-chemical Water Properties-Type III Sums of Squares

MAIN EFFECTS

	pH	**EC** (S/m)	**Turbidity** (NTU)	**COD** (mg/L)	**TP** (mg/L)	**BOD** (mg/L)	**Temp** (^{O}C)	**DO** (mg/L)	**Transparency** (meters)
A: Environment									
Sum of Squares	101.101	600	9542	6037	108205	3714.2	42.03	84.099	0.402
Df	1	1	1	1	1	1	1	1	1
Mean Squares	101.1	600.2	9541.8	6037.8	108.205	3714.2	42.031	84.099	0.402
F-Ratio	237.4807	0.3383	4.6306	7.0558	100.6586	98.2581	1.8003	143.628	5.0792
P-Value	<2e-16 ***	0.56197	0.03352 *	0.009033 **	< 2e-16 ***	< 2.2e-16 ***	0.1823	< 2.2e-16 ***	0.03006 *
B: Depth									
Sum of Squares	2.633	11699	1132	2298	5.667	1099.8	29.99	14.466	0
Df	2	2	2	2	2	2	2	2	2
Mean Squares	1.317	5849.3	565.8	1149.1	2.833	549.9	14.994	7.233	0
F-Ratio	3.0929	3.2967	0.2746	1.3431	2.6357	14.5474	0.6422	12.3733	0.00
P-Value	0.0492 *	0.04056 *	0.76038	0.265138	0.07603	2.361e-06 ***	0.5280	1.371e-05 ***	1.000
A*B (interaction)									
Sum of Squares	0.476	514	2794	4674	3.468	166.2	11.32	0.214	0
Df	2	2	2	2	2	2	2	2	2
Mean Squares	0.2238	257.2	1396.9	2336.8	122.547	83.1	5.662	0.107	0
F-Ratio	0.5593	0.1449	0.6779	2.7313	144	2.1989	0.2425	0.1831	0.00
P-Value	0.5732	0.86524	0.50971	0.069402	1.075	0.1156	0.7850	0.833	1.000
RESIDUAL	48.533	202268	234909	97537	122.547	4309.3	2661.49	530.024	3.00773
TOTAL (CORRECTED)	152.743	215.81	248377	110546	1223.71	9289.5	2536.24	629.15	3.40975

All F-ratios are based on the residual mean square error

4.2.2.1 pH

The results in table 4.5 indicates that both environment and depth significantly affect the pH of water. The p-value value (<2e-16) indicating the significance of the effect of sampling environment on water pH is far below the alpha level (0.05) which means the confidence interval for the obtained results is 100%. However, that for pH and water depth is only significant at 95% confidence interval. The results mean that water pH is significantly different in water hyacinth and open lake water as well as different lake depth. The p-value (0.5732) for the interactive effect of environment and lake depth is higher than the alpha level which illustrates that the effect of water hyacinth and water depth on water pH are independent. It means that whereas water depth affects the pH of the water, the effect of presence or absence of water hyacinth will emerge irrespective of water depth.

4.2.2.2 Electrical Conductivity

Results in table 4.5 shows that the presence or absence of water hyacinth does not significantly affect the electrical conductivity of water. The level of significance for this effect is shown by the p-value of 0.56197, which is higher than the decision rule level of 0.05. However, the results indicate that water depth significantly affect the electrical conductivity of water, with a significant rating of 95% confidence interval given the P-value of 0.04056 which is smaller than the alpha level. These results signify that EC changes with increase or decrease in lake depth but does not significantly change with presence and absence of water hyacinth. Since the P-value (0.86524) for interaction of the two factors (environment & depth) is higher than 0.05 alpha level, it reveals that there is no statistically significant effect of these factors on the water EC. The significance is that, whereas EC changes with change in water depth, these changes are not influenced by presence or absence of water hyacinth.

4.2.2.3 Turbidity

Table 4.5 reveals that water-sampling environment (water hyacinth and open lake) largely affect Turbidity as indicated by the positive F-ratio (4.63.6) and the effect is statistically significant at 95% confidence interval given the P-value (0.03352) is less than the alpha level of 0.05. The effect of the sampling depth on the other hand is indicated to have an insignificant effect on turbidity given low F ratio of 0.2746 and a P-value (0.76038) that is above the decision rule (alpha 0.5). These results signify that the water hyacinth significantly accounts for the changes in water turbidity; however, the effect of water depth on turbidity is so minimal and likely to be unnoticeable. The interactive effect of water hyacinth and water depth on turbidity too is insignificant as there is no sufficient statistical evidence to prove otherwise, given the higher P-value (0.50971) above the decision rule.

4.2.2.4 Chemical Oxygen Demand

The statistics in Table 4.5 shows that the environment significantly affects COD as indicated by the P-value (0.009033) less than 0.05. The effect of depth on the other hand was insignificant in accounting for the variations in COD, given the P-value (0.265138) higher than 0.5 decision rule. The interactive effect of the two factors (environment and depth) on COD existed but was statistically insignificant as shown by the P-value (0.069402) that is slightly above the alpha level. These results imply that water hyacinth environment accounts for significant differences in COD between water hyacinth and open lake environments. Water depth on the other hand accounts for a small variation in COD.

4.2.2.5 Total Phosphates

Table 4.5 shows that presence of water hyacinth significantly affect total phosphates in water. The level of significance for this effect is shown by the p-value of < 2e-16, which is less than the decision rule level of 0.05, thus giving a significant rating of 100%. Depth on the other hand affects total phosphates but the effect is less significant as shown by P-value slightly higher than 0.05. These results signify that a significant variation in TP is accounted for largely by presence or absence of water hyacinth than water depth. Since the P-value (0.20379) for interaction of the two factors (environment & depth) is higher than 0.05 alpha level, it means that there is no statistically significant effect of a combination of these factors on the water TP.

4.2.2.6 Biochemical Oxygen Demand

The results in Table 4.5 indicate that both environment and depth significantly affect water BOD (p-value of <2e-16 and 2.361e-06 respectively). The confidence interval for the obtained results is 100%. The results imply that changes in BOD can be accounted for by changes in lake depth as well as presence of water hyacinth. However, the combined effect of environment and depth is insignificant as shown by P-value. The results mean that significant variations in BOD in water in Murchison Bay can be explained by the independent effect of both water hyacinth and water depth.

4.2.2.7 Temperature

Table 4.5 indicates lower F-ratio values for effect of environment (0.1823), depth (0.5280) and the interactive effect of the two factors (0.7850) on water temperature. Since there are no P-values less than 0.05, none of the factors or interactions had a statistically significant effect on Temperature at the 95.0% confidence level. The implication of the results is that water temperature, changes by very small margins in response to presence or absence of water hyacinth and water depth.

4.2.2.8 Dissolved Oxygen

Table 4.5 reveals that significant variations in dissolved oxygen in Murchison Bay is largely as result of environment and depth, which means that the two factors significantly affect DO however, these act independently but when combined the two factors yield an insignificant effect. The p-value value of <2e-16 and 1.371e-05 for the significance of the effect of environment and depth respectively indicate that the effect of the two factors is statistically significant as the confidence interval for the obtained results is 100%. However, the combined effect of environment and depth is insignificant since the P-value (0.833) is less than 0.5 decision rule.

4.2.2.9 Transparency

The statistics in Table 4.5 shows that the environment greatly affects transparency, with a significance rating of 95% given the P-value (0.03006) below the decision rule. On the other hand, water depth has an insignificant contribution towards transparency given the P-value (1.00) above decision rule. The interactive effect of the two factors (environment and depth) on transparency too is statistically insignificant. These results imply that variations in water transparency is largely as a result of environment. That is, between water hyacinth and open lake environments. Water depth on the other hand accounts for minimal variation in transparency.

From the above results, the fourth research question can be answered by stating that water hyacinth negatively affects the water quality by increasing concentration of properties, Turbidity, COD, BOD, TP, and decreasing, DO, pH and transparency. These were shown to be significantly different between water hyacinth environment and open lake environment at above 95% confidence interval. The effect of water hyacinth was however shown to be insignificant on water temperature and electrical conductivity.

From the results above, above 80% of the physico-chemical water elements were significantly different between water hyacinth and open lake environments thus the second null hypothesis water hyacinth and water depth have no significant effect on the quality of water in Murchison bay was rejected in preference of the alternative

4.3 Determinants of water hyacinth extent and pattern of distribution

4.3.1 Characteristics of respondents

Out of the 201 respondents, 87% were males. 40.8% of the respondents had stayed/ operated from the area for between 11-20 years, the majority (58.2%) being fishmongers. Majority of the respondents (41.2%) indicated that, on first invasion, areal coverage of the water hyacinth in the Bay was between 6 and 10 square kilometers. The majority of respondents (41.8%) believe that the first coverage was in about 10-15 years ago. 41.2 % of the respondents believed that water hyacinth current coverage in the Bay is less than 5 square kilometers which means it has reduced as compared to the area indicated by the majority for coverage on first invasion (6-10 square meters).

4.3.2 Determinants of water hyacinth extent and distribution pattern in Murchison Bay

The results shown in Table 4.6 indicate that the respondents from the three landing sites surrounding Murchison Bay perceive that water hyacinth extent and distribution on the lake is highly influenced by factors including sheltered nature of the Bay, Sewerage effluent discharge, blowing of local winds, speed of water currents, change in lake water level, construction at the shore and Ferry Navigation. The average rating for these factors was between 2.4 to 3.24 out of 4. However, the respondents indicated that factors including water temperature, humidity, biotic colonization, hyacinth species, herbaria, water depth, fish hatcheries, and fishing gear had the least influence on water hyacinth distribution in the Bay. These were rated below 2 which on the rating scale of 4, is below average (i.e. 1.20 - 2.78 out of 4).

There results here reveal that people's perception of the determinants of water hyacinth spread is somewhat consistent with science for example, the sheltered nature of the Bay shielding the movement out of the water hyacinth and speed of water either bringing the weed into the Bay or moving it from one place to another but within the Bay. However, for the determinant factors, those respondents were not familiar with for example herbaria, biotic colonization and fish hatcheries; they were indicated to have the least influence on water hyacinth distribution. In addition, the results imply that majority of the respondents believe that much of water hyacinth proliferation is due to man's influence through sewage effluent discharge, construction works, and Ferry navigation in the Bay.

Table 4.6: Mean rating of water hyacinth determinants

No	Determinant	Mean Rating	Standard deviation
1	Sheltered Bay	3.24	0.87
2	Blowing of local winds	3.22	1.1
3	Changes in Lake water level	2.67	1.9
4	Speed of water currents	3	1.9
5	Hyacinth Species	1.42	0.67
6	Water Depth	1.53	0.83
7	Biotic Colonization	1.31	0.57
8	Temperature	1.20	0.44
9	Humidity	1.24	0.52
10	Sewerage Effluent	3.23	0.89
11	Construction at the shore	2.47	1.13
12	Establishment of fish Hatcheries	1.75	0.19
13	Establishment of botanic gardens	1.86	1.03
14	Fishing equipment/gear	1.78	1.08
15	Herbaria	1.51	0.90
16	Ferry Navigation	2.46	1.18

Pearson Chi square test of association was computed to establish whether perception for the determinants of water hyacinth extent and distribution remains the same across the three landing sites (i.e. Port Bell, Ggaba and Mulungu). The results are summarized in Table 4.7. Pearson's chi square results presented in Table 4.7 indicate that the perception of water hyacinth determent factors; that is blowing of local winds, herbaria, fishing gear, construction at the shore, change in Lake water level, fish hatcheries, ferry navigation, humidity, and biotic colonization was significantly related to respondents' location in the Bay. The p-values for these are below the threshold of 0.05. The perception of factors including temperature, sheltered Bay, speed of water, hyacinth species, water depth and botanic gardens is not significantly related to the respondents' location as their p-values fall above the threshold of 0.05. These results mean that, different factors influence water hyacinth extent and pattern of distribution (for the factors with a significant positive relationship) however there are some factors whose influence on water hyacinth extend and pattern of distribution remains the same irrespective of the spatial location in the bay (the factors shown to have a weak relationship).

Table 4.7: Pearson's Chi square results showing relationship between water hyacinth determinants and landing site

Factors	Pearson value	Likelihood rate	P-value
Sheltered Bay	4.586	4.434	0.598
Blowing of local winds	39.368	39.559	0.00
Change in lake water level	20.689	20.308	0.002
Speed of water currents	4.323	4.158	0.633
Hyacinth species genetic make-up	4.718	4.370	0.580
Water depth	14.080	16.043	0.29
Biotic colonization	12.624	16.381	0.049
Temperature	0.825	1.233	0.935
Humidity	15.738	17.526	0.015
Sewerage effluent from Nakivubo	13.532	11.278	0.35
Construction at the shore	23.681	24.516	0.001
Fish hatcheries	17.808	18.697	0.007
Botanic gardens	8.310	8.493	0.216
Fishing Boats & nets	33.056	40.264	0.000
Herbaria	29.059	28.080	0.000
Ferry navigation	19.486	23.398	0.012

From the results above, the null hypothesis that there is no significant difference in the factors determining water hyacinth extent and pattern of distribution across Murchison Bay is rejected in preference to the alternative hypothesis.

CHAPTER FIVE: DISCUSSION

5.0 Introduction

This chapter presents discussion of the study findings, following the study objectives.

5.1 Discussion

5.1.1 Mapping the extent and distribution pattern of water hyacinth in Murchison Bay

It was established that water hyacinth concentrated more on the northern edges of Murchison Bay although in 2016 and 2018 it slightly increased on the western and eastern edges. The area under water hyacinth was discovered to be non-uniform and dynamic although the weed covered the smallest area that is less than 5 % over the four-year period as compared to other land covers. That is water hyacinth extent and pattern of distribution varied largely over space and time (Table 4.1. Figure 4.1:2). With decrease in open water surface came increase in areal coverage of the water hyacinth in the Bay.

The increase in water hyacinth extent like in 2017 and 2019 over Murchison Bay is related to the findings in a study by Verma et al. (2003) while assessing changes in water hyacinth coverage over water bodies in Northern Bangalore using Indian Remote Sensing Satellite LISS-II and III images of the years, 1988–2001. Their study indicated that area under water hyacinth increased in the recent years which consequently reduced the area under open water. The major areas of contention in the current study findings with those of Verma et al. (2003) are due to the fact that water hyacinth coverage changes alternated between increase and decrease over the years. However, what stands out in the present study is that water hyacinth increased from 1% in 2016 to 4% in 2019.

The study also revealed that water hyacinth distribution varied over space and time. These could be explained by the differences in seasons and general environmental conditions' dynamism. While assessing the effect of water hyacinth on physico-chemical characteristics of Lake Naivasha, Mironga et al. (2016) established that there was a high growth of the water hyacinth in all the sampled areas especially during the wet season. Albright et al. (2004) also reports that a combination of factor including conditions associated with the 1997 to1998 El Niño contributed to a major decline in water hyacinth in Kagera basin in the late 1990s. This means that changes in seasons cause spatial shifts in water hyacinth coverage generally. This is in line with the results by Thamaga and Dube (2018)'s study involving mapping and understanding the Spatio-temporal distribution of invasive water hyacinth in the Greater Lateba river system in Tzaneen, Limpopo Province of South Africa using Landsat 8 OLI and Sentinel-2 MSI data. Their study established that the wet season had high coverage of water hyacinth than the dry season.

The present study established that the water hyacinth mainly concentrated on the northern parts of Murchison Bay. This revelation is also echoed in Albright et al. (2004) who reported that the water hyacinth attained a maximum lake-wide extent of approximately 17,374 ha by 1998 on the northern shores of Lake Victoria to which the Murchison Bay belongs. This points towards area of intervention in terms of control of the water weed.

Kigundu et al. (2017) while assessing land use and land cover changes in Murchison Bay catchment of Lake Victoria Basin in Uganda reports huge land use changes which pose a threat to the environment and water quality of the Murchison Bay and consequently increases National Water and Sewerage Corporation water treatment costs. Whereas the focus of Kigundu et al. (2017)'s study was on changes in built-up land, and open water bodies and agricultural lands, forestland and wetlands, some of these changes have been reflected in the results obtained under the current study where put under perspective. For example, area under open lake under Kigundu et al. (2017)'s study was indicated to have fluctuated between 1984 and 2015. Where lake open surface reduced, the implication could be that this is time water hyacinth increased in cover over the lake. The current study revealed that increase in water hyacinth area was accompanied by decrease in open lake area.

5.1.2 Effect of water hyacinth on physico-chemical water quality properties

The analysis of data on various water quality parameters indicated significant differences as shown by the mean values between water hyacinth and open water environments (Table 4.4). The effect of water hyacinth on water quality was significant for parameters including pH, TP, BOD, COD, DO, turbidity and transparency but not on water temperature and electrical conductivity. This means that water hyacinth significantly changed water physico-chemical characteristics negatively.

It was established that water hyacinth lowers water pH as mean values of these were significantly higher (8.5) in open lake than under water hyacinth environments (6.7), although in each of these cases, the values are within the WHO (2020) permissible limits for drinking water (Appendix IV). This was also true with Mirongo et al. (2016)'s study which established that pH was significantly lower ($P<0.05$) in water hyacinth infested areas (6.92 ± 0.04) than in open water (7.71 ± 0.05). pH is one of the most important parameters of water quality. It is a measure of how acidic/basic water is (White et. al, 1997). Acidic water contains extra hydrogen ions (H^+) and basic water contains extra hydroxyl (OH^-) ions (White et al., 1997). For treated water, excessively high and low pH can be detrimental for the use of water. A high pH makes the taste bitter and decreases the effectiveness of the chlorine disinfection, thereby causing the need for additional chlorine (Spellman, 2017). The amount of oxygen in water increases as pH rises. Low-pH water will corrode or dissolve metals and other substances. Most aquatic animals and plants have adapted to life in water with a specific pH and may suffer from even a slight change. Even moderately acidic water (low pH) can decrease the number of hatched fish eggs, irritate fish and aquatic insect gills, and damage membranes. Water with very low or high pH is fatal. A pH below 4 or above 10 will kill most fish, and very few animals can endure water with a pH below 3 or above 11. Amphibians are extremely endangered by low pH because their skin is very sensitive to contaminants. Some scientists believe that the current decrease in amphibian population throughout the globe may be due to low pH levels (DeZuane, 1997). Extremes of pH can affect the palatability of water but the corrosive effect on distribution systems is a more urgent problem. Apart from the aspects just mentioned, pH values govern the behavior of several other important parameters of water quality. Ammonia toxicity, chlorine disinfection efficiency and metal solubility are all influenced by pH, for example. In terms of water treatment, pH determines coagulants used at NWSC-Ggaba such as Aluminium Sulphate (ALUM). ALUM has a pH working range of between 6.5- 8.5, both extremes reduce the rate of coagulation and hence resulting in use of large amounts of the chemicals with minimal effectiveness. Chlorine is the main disinfection chemical used at Ggaba plant, the most favorable working pH of chlorine is 5.5-6.5, high pH results in increased chlorine demand and hence large volume will be required to disinfect the same volume of water.

Water hyacinth was also established to have a significant effect on Biochemical Oxygen Demand. The mean BOD for water samples from water hyacinth were higher (33 mg/l) as compared to those for water samples from open lake environments (22 mg/l). In each of these cases, the BOD values are far beyond the maximum permissible WHO values (10 mg/l) (WHO, 2020). Bacteria and other microorganisms use organic substances for food. As they metabolize organic material, they consume oxygen (APHA, 2015). The organics are broken down into simpler compounds, such as CO_2 and H_2O, and the microbes use the energy released for growth and reproduction. When this process occurs in water, the oxygen consumed is the DO in the water. If oxygen is not continuously replaced by natural or artificial means in the water, the DO concentration will reduce as the microbes decompose the organic materials. This need for oxygen is called the biochemical oxygen demand (BOD). The more organic material there is in the water, the higher the BOD used by the microbes will be. The fact that BOD was higher under water hyacinth environments justifies the fact that water hyacinth increases the need for oxygen in water. No, wonder the mean values of dissolved oxygen under water hyacinth environments in this study were discovered to be significantly lower compared to those under open lake environment (Table 4.4). Higher values of BOD indicate presence of organic matter, which would rather support microbial growth and also consume a lot of chlorine for disinfection. Water with high values of BOD results in increased use of coagulants to achieve effective clarification of water. Even though BOD has no direct health implications, it is an important indicator of overall water quality.

In the study, water hyacinth was shown to significantly increase water turbidity. Since turbidity is caused by suspended material (Alley, 2017), it is eminent that the water hyacinth definitely increases such materials especially organic particles in the water. The turbidity of results from both open Lake and water hyacinth environments were higher than the WHO permissible limits for drinking water (Appendix IV) which means the water in Murchison Bay is generally unfit for consumption without amendments. The implication of increased turbidity includes; increase in solids that are non-filterable by routine methods, increase in disinfection process costs, risk of pathogenic organism's inhabitation and non-acceptability by water consumers. Turbidity presents difficulty in water treatment since more chemicals will be required for coagulation and disinfection (Cole et al., 1999). It also affects the rate of filtration in water treatment since the filter run time reduces and more water is required for back wasting the filters. Suspended materials can clog or damage fish gills, decreasing its resistance to diseases, reducing its growth rates, affecting egg and larval maturing, and affecting the efficiency of fish catching method. Suspended particles provide absorption media for heavy metals such as mercury, chromium, lead, cadmium, and many hazardous organic pollutants such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and many pesticides.

It was also established that water hyacinth affects water quality by increasing the Chemical Oxygen Demand of the water while open water environments exert a lower chemical oxygen demand on the water body. COD is a measure of the biodegradable and the non-biodegradable substances in water that is, all organics. It is also an indicator of overall water quality. Increasing COD values indicate increasing organic matter in the water. This has a direct implication on water treatment, as water with high organic matter requires higher doses of the coagulants to achieve effective clarification of water. Similarly, water with a high COD has a high chlorine demand and will require high chlorine dozes to fully disinfect. This is also because high COD values are associated with increased organic pollution into the water. Results in the present study indicates that COD values from water hyacinth environment are slightly above the WHO permissible level (APPENDIX: VI).

The study established that water hyacinth lowers the amount of Dissolved Oxygen in Murchison Bay, as the mean values for the same were higher in open lake as compared to those under water hyacinth environment. The differences in DO between water hyacinth and open lake environments were significant at above 95% although the values for water hyacinth environment were close to the maximum permissible lime of 6.0 mg/l, compared to those from open lake (WHO, 2020). Mironga et al. (2016) study also revealed similar findings when they compared DO for water hyacinth and open water areas on Lake Naivasha and established that DO was significantly lower ($P<0.05$) in the infested areas (1.96±0.71 mgL^{-1}) compared to open water areas (5.98±0.85 mgL^{-1}). This means that the water weed (water hyacinth) significantly reduces the amount of Dissolved oxygen in water over Murchison Bay. The current study findings are related to those by Villamagna and Murphy (2010) who reported that large water hyacinth mats prevent the transfer of oxygen from the air to the water surface, or decrease oxygen production by other plants and algae. When the plant dies and sinks to the bottom, the decomposing biomass depletes oxygen content in the water body (EEA, 2012). Dissolved oxygen is considered one of the most important parameters of water quality in streams, rivers, and lakes. It is a key test of water pollution (APHA, 2015). The higher the concentration of dissolved oxygen, the better the water quality. The actual amount of dissolved oxygen varies depending on pressure, temperature, and salinity of the water. For treated portable water, dissolved oxygen has no direct effect on public health, but drinking water with very little or no oxygen tastes unpalatable to some people. In terms of health implications, DO has a slightly organoleptic significance only, but critical for survival of fish. Although DO does not affect water treatment costs, it is a significant indicator of water quality.

Water transparency was also established to be different between water hyacinth and water hyacinth environments while low mean values were registered under water hyacinth environment, meaning that water hyacinth affects water quality by reducing its transparency. Thamaga and Dube (2018) states water hyacinth can impact zooplankton and phytoplankton productivity in freshwater ecosystem, modify surface water clarity and cause hypoxia or a decrease in the concentration of related nutrients and contaminants, such as nitrogen, phosphorous and heavy metals. Water transparency is a key factor in lake water (water bodies) as the sun is source of energy for all biological phenomena. Reduced transparency indicates possible loss of water quality and signifies presence of suspended matter, living or inert, and hence it is a reflection of the overall quality of water. However, the presence of any undesirable substances in solution will not be indicated by transparency. In terms of treatment costs, increased transparency results in increased photosynthesis rates and hence formation of algal blooms. As a result, more coagulants required to treat water with large amounts of algae. Water with high algal content also consumes a lot of chlorine during pre-oxidation to reduce on organic matter.

5.1.3 Determinants of water hyacinth extent and pattern of distribution in Murchison Bay

This study established sheltered nature of the Bay, sewerage effluent discharge, blowing of local winds, speed of water, change in lake water level, construction at the shore and ferry navigation strongly determine water hyacinth pattern and distribution in Murchison Bay as perceived by the respondents although with variations in the level of influence (Table 4.6 & 4.7). The average rating for these factors was between 2.4 to 3.24 out of 4. However, water temperature, humidity, biotic colonization, hyacinth species, herbaria, water depth, fish hatcheries, and fishing gear were perceived to have the least influence on water hyacinth extent and distribution in the Bay. These were rated below 2 which on the rating scale of 4 is below average.

Whereas human related factors were among these indicated in this study as being responsible for water hyacinth distribution in Murchison Bay. In a study by Verma et al. (2003) the increased coverage of the water hyacinth was accounted for human activities in the catchment such as agriculture and settlement from where agricultural run-off and sewerage are let into the water body, having excess nutrients which are absorbed by water hyacinth thus increasing the area under cover.

The study established that water hyacinth extent and distribution in Murchison Bay is influenced by speed of water, which received a mean rating of 3 out of 4. This revelation is directly implied in the Téllez et al. (2008) report that currents constitute the dispersion of water hyacinth propagule and stalons which makes the weed to get distributed and colonize new areas within a short time. Speed of water currents is thus a biotic factor for colonization of new areas with considerable importance for the potential propagation of the infestation in a given territory.

The survey revealed that temperature and humidity have insignificant influence on water hyacinth extent and distribution in Murchison Bay. The overall temperatures and humidity over the Bay are however generally high (above 18 ^{0}C and 70% respectively) on average. This means these two factors have high influence on water hyacinth coverage in the Bay, which is concomitant with Gichuki et al. (2012)'s statement that water hyacinth can grow well in high temperatures, ranging between 25^{o}C and 27^{o}C (Gichuki et al., 2012). Similarly, Bhattacharya et al. (2015) report that the number of daughter plants is greatest at a certain level of temperature and relative humidity (day/night temperatures of 25^{o}C/20^{o}C to 40/25^o C and relative humidity of 15/40% to 75/95% as according experimental studies under controlled laboratory conditions. Growth stops if the water temperature falls between 10^{o}C or rises above 40^o C according to Zhang et al. (2010).

The current study also indicated that the influence of water depth on water hyacinth extent and distribution is minimal (with an average rating of 1.53 mean rating out of 4) as perceived by the respondents in Murchison Bay catchment. However, previous studies have shown that both the depth of the water and changes in lake water levels are important for the growth and expansion of water hyacinth. The reports suggest that the plants have more roots in deep waters than in shallow waters, while the leaf area and the summer growth of the plant are greater in shallow waters according to Dube et al. (2015)'s study indicated that water hyacinth is less concentrated on rivers that are characterized by major fluctuations in the water levels. This implies that whereas people in Murchison Bay think that water depth plays an insignificant role on water hyacinth distribution, and extent, the factor is crucial as even the results from mapping showed more concentration of the water hyacinth on the shores of the lake where lake depth significantly reduces.

Water hyacinth's species genetic makeup was perceived to also have less influence on the distribution of the waterweed. The current study findings however contend with the findings by Wilgen and Lange et al. (2011) who indicate that, variations in the invasive potential of the water hyacinth reflect its preference for the new habitat and the availability of propagules. Thus, the species' genetic makeup, which is responsible for its reproductive strategy and capacity for the plant growth, is of great importance in contributing to the invasion. Further, studies (Shanab et al., 2010; Villamagna et al., 2010; Khanna et al., 2012) indicate that water hyacinth has an extraordinary growth rate. This has been calculated to be an increase in biomass of 400-700 tons per day or an increase in water area coverage by factor 1.012-1.077 per day. This therefore means the extent and distribution of water hyacinth over Murchison Bay cannot be wholly accounted for without putting into consideration that the water hyacinth in its genetic nature is highly invasive. The divergences in between current study results and those in the literature can be explained by the fact that the biggest proportion of the residents in Murchison Bay were not plant ecologist and thus have little scientific understanding of the water hyacinth.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.0 Introduction

This chapter presents conclusions and recommendations derived from the key study findings. The recommendations cover areas related to policy and future research needs.

6.1 Conclusions

Basing on the study findings, three conclusions were arrived at with reference to the study objectives.

1. The extent and distribution of the water hyacinth in Murchison Bay varies over space and time but is more concentrated on the northern shores. The results revealed shifts and differences in areal coverage of water hyacinth in the Bay over the four-year period (2016-2019). Water hyacinth coverage increased from 1% to 4% between 2016 and 2019 whilst concentration was more on the northern and western parts of the Bay.
2. Water hyacinth significantly affects water quality, in some cases beyond the WHO permissible limits (Appendix: IV).Results from this study (Table: 4.4) indicates that parameters such as DO, Turbidity, pH, BOD, and total phosphates are not within the permissible range of WHO, 2020 guidelines. Descriptive statistics results indicated significant differences in water quality properties between water hyacinth and non-water hyacinths environments whilst the Two-way ANOVA results indicated significant effect of sampling environment on water quality parameters including pH, DO, COD, BOD, Turbidity, TP and Transparency but not EC, and temperature (with P-values > 0.05). The effect of sampling depth was only significant on pH, EC, BOD and DO whilst the interactive effect of environment and depth was insignificant for all water quality parameters. The null hypothesis that water hyacinth and water depth have no significant effect on water quality of in Murchison Bay is thus rejected in preference of the alternative.

3. The determinant factors of water hyacinth extent and distribution pattern largely vary over space. The Pearson's chi square results revealed a significant positive relationship between the three study sites (Port Bell, Ggaba & Mulungu) and water hyacinth determent factors; blowing of local winds, herbaria, fishing gear, construction at the shore, change in lake water level, fish hatcheries, ferry navigation, humidity, and biotic colonization (with p-values < 0.05). The null hypothesis that there is no significant difference in the factors determining water hyacinth extent and pattern of distribution over space was rejected in preference to the alternative.

6.2 Recommendations

Basing on the findings in this study, a number of recommendations are made to address issues that are related to the effect of water hyacinth on water quality.

Measures to control water hyacinth proliferation in Murchison bay should proceed from the northern and northeastern parts of the Bay. These were shown in this study to have the highest concentration of water hyacinth over the studied period and thus require more management.

Sewerage and other effluents discharged into Murchison Bay actions should be managed by controlling human actions in Murchison Bay catchment. Water resources management departments in Uganda should promote mass education campaigns through which people living around water bodies can be sensitized about the human activities contributing towards proliferation of the water hyacinth pattern and thus regulate these accordingly. The directorate of wetlands and water resources management, NEMA and NWSC should involve the residents around water bodies in the drawing of plans to control water pollutants including the water hyacinth.

Water for human consumption should be extracted from open Lake Environments. This study indicated that water quality deteriorates considerably under water hyacinth environments. It was established that water hyacinth concentrated in the Bay is partly as a result of being sheltered. Thus, alternative sites that do not allow water hyacinth concentration should be considered for future water harvesting stations development.

Future research involving long-term monitoring of water quality parameters under water hyacinth infested areas in Murchison Bay is necessary to determine emergent difference related to longer temporal variations.

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APPENDICES

Appendix I: GPS points for water sampling locations in Murchison Bay

Site ID	Easting	Northing
P1_G	459762	31265
P2_M2	461347	32087
p2_E	459539	32308
P1 _M1	459917	31866
P3_D	460275	32070
P3_M3	462586	32195
P4_A	461381	32074
P4_M4	459793	31274
P5_P	462035	31828
P5_M5	461351	31345
P6_N	462608	32541
P7_M7	462126	31061
P7_L	462760	27352
P8_M8	463302	31053
P9_K	462438	27060
P9_M9	460984	32207
P10_J	461120	26162
P_M16	461759	27972
P11_Q	460005	26934
P_M18	459621	27107
P12 XX	459645	27236

Appendix II: Data Collection Form: Water Hyacinth extent and distribution pattern factors

Please read carefully and tick ☐ or write as instructed

Participant Background Data

1. Gender (Male/ Female)? Male ☐ Female☐

2. How long have you lived/worked in Murchison Bay area?

0-5 years	
6-10 years	
11-20 years	
>20 years	

3. Age

1-18 years	
19-36 years	
37-54 years	
>55 years	

4. What is your occupation (write the institution you are working with as well if applicable)?

……………………………………………………………………………………

Perceived Water Hyacinth Distribution Pattern and Extent

5. When did you first realize existence of water hyacinth in Murchison Bay?

0-5 years back	
6-10 years back	
11-20 years back	
>20 years back	

(a) Approximately how much area was covered the water hyacinth when it first invaded the Bay?

1-100 m^2	
101-200 m^2	
201-300 m^2	
301-400 m^2	
401-500 m^2	
> 500 m^2	

(b) Approximately how much area is covered by the water hyacinth in Murchison Bay?

Less than 500km^2	
501-1000 m^2	
1001-1500 m^2	
1501-2000 m^2	
>2000 m^2	

Perceived Determinants of Water Hyacinth Distribution Pattern and Extent

(a) Rate the determinant factors of water hyacinth distribution and extent in Murchison Bay on the scale of 1- 4, where 1 means a given factor has least influence and 4 means a factor is highly influential.

To what extent do the following factors determine Hyacinth Distribution in	Rate on a scale of 1-4			
Natural Factors	4	3	2	1
Sheltered Bay				
Blowing of local winds				
Changes in Lake water level				
Speed of water currents				
Hyacinth Species Genetic make-up				
Depth of Lake water level				
Biotic colonization				
Temperature				
Humidity				
Human Factors				
Sewerage effluent from Nakivubo Channel				
Constructions at the shore				
Fish hatcheries				
Botanic Gardens (garden flowers)				
Fishing Boats and Nets (Fishing gear)				
Herbaria's (weed experiments)				
Ferry Transport (Navigation)				

(b) Any Other factors/ comments on distribution of water hyacinth in Murchison Bay

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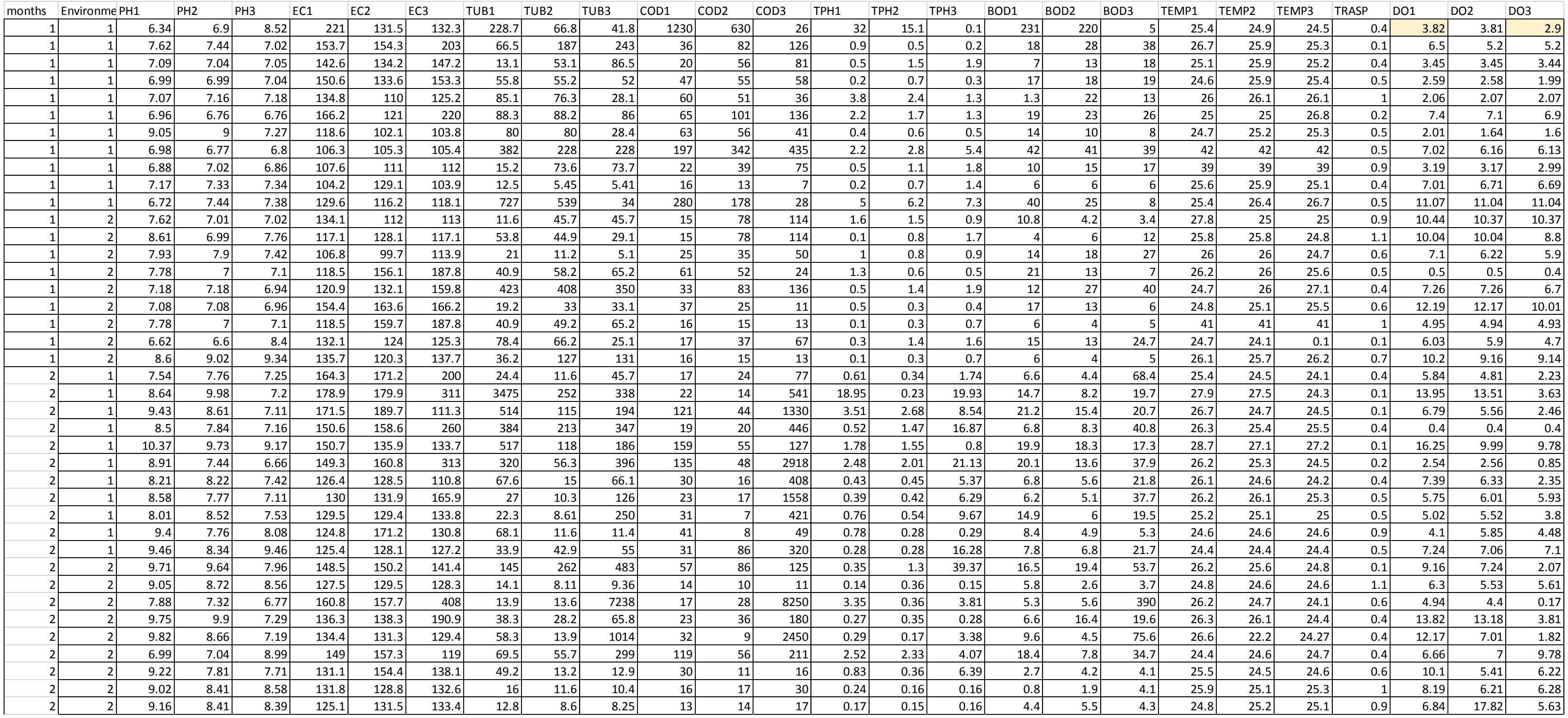
Appendix III: Water quality data used in the study



months	Environme	PH1	PH2	PH3	EC1	EC2	EC3	TUB1	TUB2	TUB3	COD1	COD2	COD3	TPH1	TPH2	TPH3	BOD1	BOD2	BOD3	TEMP1	TEMP2	TEMP3	TRASP	DO1	DO2	DO3
1	1	6.34	6.9	8.52	221	131.5	132.3	228.7	66.8	41.8	1230	630	26	32	15.1	0.1	231	220	5	25.4	24.9	24.5	0.4	3.82	3.81	2.9
1	1	7.62	7.44	7.02	153.7	154.3	203	66.5	187	243	36	82	126	0.9	0.5	0.2	18	28	38	26.7	25.9	25.3	0.1	6.5	5.2	5.2
1	1	7.09	7.04	7.05	142.6	134.2	147.2	13.1	53.1	86.5	20	56	81	0.5	1.5	1.9	7	13	18	25.1	25.9	25.2	0.4	3.45	3.45	3.44
1	1	6.99	6.99	7.04	150.6	133.6	153.3	55.8	55.2	52	47	55	58	0.2	0.7	0.3	17	18	19	24.6	25.9	25.4	0.5	2.59	2.58	1.99
1	1	7.07	7.16	7.18	134.8	110	125.2	85.1	76.3	28.1	60	51	36	3.8	2.4	1.3	1.3	22	13	26	26.1	26.1	1	2.06	2.07	2.07
1	1	6.96	6.76	6.76	166.2	121	220	88.3	88.2	86	65	101	136	2.2	1.7	1.3	19	23	26	25	25	26.8	0.2	7.4	7.1	6.9
1	1	9.05	9	7.27	118.6	102.1	103.8	80	80	28.4	63	56	41	0.4	0.6	0.5	14	10	8	24.7	25.2	25.3	0.5	2.01	1.64	1.6
1	1	6.98	6.77	6.8	106.3	105.3	105.4	382	228	228	197	342	435	2.2	2.8	5.4	42	41	39	42	42	42	0.5	7.02	6.16	6.13
1	1	6.88	7.02	6.86	107.6	111	112	15.2	73.6	73.7	22	39	75	0.5	1.1	1.8	10	15	17	39	39	39	0.9	3.19	3.17	2.99
1	1	7.17	7.33	7.34	104.2	129.1	103.9	12.5	5.45	5.41	16	13	7	0.2	0.7	1.4	6	6	6	25.6	25.9	25.1	0.4	7.01	6.71	6.69
1	1	6.72	7.44	7.38	129.6	116.2	118.1	727	539	34	280	178	28	5	6.2	7.3	40	25	8	25.4	26.4	26.7	0.5	11.07	11.04	11.04
1	2	7.62	7.01	7.02	134.1	112	113	11.6	45.7	45.7	15	78	114	1.6	1.5	0.9	10.8	4.2	3.4	27.8	25	25	0.9	10.44	10.37	10.37
1	2	8.61	6.99	7.76	117.1	128.1	117.1	53.8	44.9	29.1	15	78	114	0.1	0.8	1.7	4	6	12	25.8	25.8	24.8	1.1	10.04	10.04	8.8
1	2	7.93	7.9	7.42	106.8	99.7	113.9	21	11.2	5.1	25	35	50	1	0.8	0.9	14	18	27	26	26	24.7	0.6	7.1	6.22	5.9
1	2	7.78	7	7.1	118.5	156.1	187.8	40.9	58.2	65.2	61	52	24	1.3	0.6	0.5	21	13	7	26.2	26	25.6	0.5	0.5	0.5	0.4
1	2	7.18	7.18	6.94	120.9	132.1	159.8	423	408	350	33	83	136	0.5	1.4	1.9	12	27	40	24.7	26	27.1	0.4	7.26	7.26	6.7
1	2	7.08	7.08	6.96	154.4	163.6	166.2	19.2	33	33.1	37	25	11	0.5	0.3	0.4	17	13	6	24.8	25.1	25.5	0.6	12.19	12.17	10.01
1	2	7.78	7	7.1	118.5	159.7	187.8	40.9	49.2	65.2	16	15	13	0.1	0.3	0.7	6	4	5	41	41	41	1	4.95	4.94	4.93
1	2	6.62	6.6	8.4	132.1	124	125.3	78.4	66.2	25.1	17	37	67	0.3	1.4	1.6	15	13	24.7	24.7	24.1	0.1	0.1	6.03	5.9	4.7
1	2	8.6	9.02	9.34	135.7	120.3	137.7	36.2	127	131	16	15	13	0.1	0.3	0.7	6	4	5	26.1	25.7	26.2	0.7	10.2	9.16	9.14
2	1	7.54	7.76	7.25	164.3	171.2	200	24.4	11.6	45.7	17	24	77	0.61	0.34	1.74	6.6	4.4	68.4	25.4	24.5	24.1	0.4	5.84	4.81	2.23
2	1	8.64	9.98	7.2	178.9	179.9	311	3475	252	338	22	14	541	18.95	0.23	19.93	14.7	8.2	19.7	27.9	27.5	24.3	0.1	13.95	13.51	3.63
2	1	9.43	8.61	7.11	171.5	189.7	111.3	514	115	194	121	44	1330	3.51	2.68	8.54	21.2	15.4	20.7	26.7	24.7	24.5	0.1	6.79	5.56	2.46
2	1	8.5	7.84	7.16	150.6	158.6	260	384	213	347	19	20	446	0.52	1.47	16.87	6.8	8.3	40.8	26.3	25.4	25.5	0.4	0.4	0.4	0.4
2	1	10.37	9.73	9.17	150.7	135.9	133.7	517	118	186	159	55	127	1.78	1.55	0.8	19.9	18.3	17.3	28.7	27.1	27.2	0.1	16.25	9.99	9.78
2	1	8.91	7.44	6.66	149.3	160.8	313	320	56.3	396	135	48	2918	2.48	2.01	21.13	20.1	13.6	37.9	26.2	25.3	24.5	0.2	2.54	2.56	0.85
2	1	8.21	8.22	7.42	126.4	128.5	110.8	67.6	15	66.1	30	16	408	0.43	0.45	5.37	6.8	5.6	21.8	26.1	24.6	24.2	0.4	7.39	6.33	2.35
2	1	8.58	7.77	7.11	130	131.9	165.9	27	10.3	126	23	17	1558	0.39	0.42	6.29	6.2	5.1	37.7	26.2	26.1	25.3	0.5	5.75	6.01	5.93
2	1	8.01	8.52	7.53	129.5	129.4	133.8	22.3	8.61	250	31	7	421	0.76	0.54	9.67	14.9	6	19.5	25.2	25.1	25	0.5	5.02	5.52	3.8
2	1	9.4	7.76	8.08	124.8	171.2	130.8	68.1	11.6	11.4	41	8	49	0.78	0.28	0.29	8.4	4.9	5.3	24.6	24.6	24.6	0.9	4.1	5.85	4.48
2	1	9.46	8.34	9.46	125.4	128.1	127.2	33.9	42.9	55	31	86	320	0.28	0.28	16.28	7.8	6.8	21.7	24.4	24.4	24.4	0.5	7.24	7.06	7.1
2	2	9.71	9.64	7.96	148.5	150.2	141.4	145	262	483	57	86	125	0.35	1.3	39.37	16.5	19.4	53.7	26.2	25.6	24.8	0.1	9.16	7.24	2.07
2	2	9.05	8.72	8.56	127.5	129.5	128.3	14.1	8.11	9.36	14	10	11	0.14	0.36	0.15	5.8	2.6	3.7	24.8	24.6	24.6	1.1	6.3	5.53	5.61
2	2	7.88	7.32	6.77	160.8	157.7	408	13.9	13.6	7238	17	28	8250	3.35	0.36	3.81	5.3	5.6	390	26.2	24.7	24.1	0.6	4.94	4.4	0.17
2	2	9.75	9.9	7.29	136.3	138.3	190.9	38.3	28.2	65.8	23	36	180	0.27	0.35	0.28	6.6	16.4	19.6	26.3	26.1	24.4	0.4	13.82	13.18	3.81
2	2	9.82	8.66	7.19	134.4	131.3	129.4	58.3	13.9	1014	32	9	2450	0.29	0.17	3.38	9.6	4.5	75.6	26.6	22.2	24.27	0.4	12.17	7.01	1.82
2	2	6.99	7.04	8.99	149	157.3	119	69.5	55.7	299	119	56	211	2.52	2.33	4.07	18.4	7.8	34.7	24.4	24.6	24.7	0.4	6.66	7	9.78
2	2	9.22	7.81	7.71	131.1	154.4	138.1	49.2	13.2	12.9	30	11	16	0.83	0.36	6.39	2.7	4.2	4.1	25.5	24.5	24.6	0.6	10.1	5.41	6.22
2	2	9.02	8.41	8.58	131.8	128.8	132.6	16	11.6	10.4	16	17	30	0.24	0.16	0.16	0.8	1.9	4.1	25.9	25.1	25.3	1	8.19	6.21	6.28
2	2	9.16	8.41	8.39	125.1	131.5	133.4	12.8	8.6	8.25	13	14	17	0.17	0.15	0.16	4.4	5.5	4.3	24.8	25.2	25.1	0.9	6.84	17.82	5.63

Appendix IV: World Health Organization permissible limits of selected water quality parameters

Parameters	**WHO maximum permissible limits**
pH (unit)	6.5 - 8.5
EC (mS/m)	400
Turbidity (NTU)	5.0
BOD (mg/l)	10
DO (mg/l)	6.0
COD (mg/l)	10 - 20
Total Phosphates (mg/l)	0.3 - 5
Temperature (degrees Celsius)	24^0 - 30^o
Transparency	----------

Source: WHO, 2020.