Impact of water hyacinth infestation in Nigerian inland waters: utilization and management

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IMPACT OF WATER HYACINTH INFESTATION IN NIGERIA INLAND WATERS: UTILIZATION AND MANAGEMENT

By

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NIGERIA

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DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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(Date): 24th September, 2019

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May God Almighty bless and keep you all safe.
Title of Dissertation: **Impact of Water Hyacinth Infestation in Nigeria Inland waters: Utilization and Management.**

**Degree:** MSc.

This work examines the spread of water hyacinth in Nigerian freshwater bodies and examines possible ways of managing the spread of the plant and explores ways of using the harvested plants. The origin and spread of the plant were examined through history as it was discovered in South America in 1816 and spread to New Orleans, Louisiana, the United States in 1884. It spread into Australia, Asia, the Middle East and Africa through the influence of human activities. Water hyacinth was discovered in 1984 in Nigeria along the Badagry creek Lagos and from 1992, it spread to the coastline of 20 states of the 36 states in Nigeria.

The proliferation of water hyacinth in Nigeria freshwater ecosystem clogs waterways and prevents navigation, it alters the ecology of water, thereby disrupting fishing activities and prevents hydroelectric power generation.

The ways of limiting its spread using biological, chemical, physical and integrated control methods were examined by highlighting the benefits and disadvantages of each method. Furthermore, a controlled experiment was conducted indoors to establish the efficacy of the use of some environmentally friendly chemicals like acetic acid, formic acid and citric acid in controlling the spread of water hyacinth.

The potential economic utilization of the harvested plant were evaluated and were found that both the fresh plant biomass and the dry weight could act as raw materials for fish and animal feed, fibreboard, yarn and rope, baskets, for biogas production, for ethanol production, for liquid oil production, for fertilizer production, for pharmaceutical products and as bio-sorbent.

The concluding chapters outlined some recommendations for the control and management of water hyacinth infestation in Nigeria.

**KEYWORDS:** Water hyacinth, spread, Nigeria, impact, control, experiment, Utilization.
Table of Contents

Declaration................................................................................................................... ii
Acknowledgements..................................................................................................... iii
Abstract....................................................................................................................... iv

Table of Contents......................................................................................................... v

List of Figures............................................................................................................... Error! Bookmark not defined.

List of Tables ............................................................................................................ viii
List of Abbreviations .................................................................................................. ix

Chapter 1 Introduction............................................................................................ 1
  1.0 Introduction ....................................................................................................... 1
  1.1 Problem Statement .......................................................................................... 5
  1.2 Objective of the Study ..................................................................................... 6
  1.3 Historical Background of Nigeria .................................................................... 7
  1.4 Study Area ...................................................................................................... 9
  1.5 Literature Review ......................................................................................... 10

Chapter 2 Literature Review.................................................................................. 14
  2.0 Introduction .................................................................................................... 14
  2.1 Characteristics of Water Hyacinth ................................................................. 14
  2.2 Taxonomy ..................................................................................................... 15
  2.3 Morphology ................................................................................................. 16
  2.4 Biology ........................................................................................................ 17
  2.5 Ecology ....................................................................................................... 18
  2.6 Chemistry of Water Hyacinth ...................................................................... 19
  2.7 Habitat .......................................................................................................... 20
  2.8 Geographical Distribution ............................................................................. 20
  2.9 Distribution in Nigeria ................................................................................... 21
  2.10 Elements Controlling the Growth and Spread of Water Hyacinth in Nigeria .................................................................................................................. 24
  2.11 Impacts of Water Hacinth Infestation in Nigeria .......................................... 25

Chapter 3 Research Methodology ....................................................................... 28
  3.0 Research Design ............................................................................................. 28
  3.1 Methodology ................................................................................................. 28
  3.2 Collection of Primary Data using Questionnaires .......................................... 28
  3.3 Testing of Some Environmentally Acceptable Herbicides .............................. 29
  3.4 Study Area .................................................................................................... 29

Chapter 4 Utilization of Water Hyacinth .............................................................. 30
  4.0 Fish and Animal Feed .................................................................................... 30
  4.1 Raw Material for the Industry ....................................................................... 31
  4.2 Raw Material for the Production of Biogas .................................................... 32
List of Tables

TABLE 1: Scientific classification of water hyacinth………………….15
TABLE 2: Spatial distribution of water hyacinth in Nigerian inland waters…….23
TABLE 3: Effects of acetic, formic and citric acid at different concentrations on the growth of aquatic weed under controlled conditions………….39
List of Figures

Figure 1: Some benefits of the world's oceans……………………………………..1
Figure 2: Water hyacinth plant……………………………………………………..5
Figure 3: Map of Nigeria…………………………………………………………...7
Figure 4: Map of Nigeria showing major inland waters…………………………9
Figure 5: Morphology of water hyacinth plants…………………………………..16
Figure 6: Water Hyacinth Chemical Structure…………………………………..19
Figure 7: Water lettuce before the experiment………………………………….40
Figure 8: Start of application of acetic, formic and citric acid………………….40
Figure 9: Effect of acetic acid after two hours of application…………………..41
Figure 10: Experiment after five days of application…………………………..41
Figure 11: Effect of acetic, formic and citric acid after five days of application…42
List of Abbreviations
ADB: African Development Bank
AERF: Aquatic Ecosystem Restoration Foundation
AME: Africa and the Middle East
AUG: Australian Government
BOD: Biochemical Oxygen Demand
CABI: Centre for Agricultural and Bioscience International
CIMP: Coordinated Integrated Management Project
COD: Chemical Oxygen Demand
CSC: United Kingdom Commonwealth Science Council
CSIRO: Commonwealth Scientific and Industrial Organization
DFID: United Kingdom Department for International Development
ECOWAS: Economic Community of West African States
EPPO: European and Mediterranean Plant Protection Organization
FAO: Food and Agricultural Organization
FDI: Foreign Direct Investment
FRN: Federal Republic of Nigeria
GDP: Gross Domestic Products
GTZ: Gesellschaft für Technische Zusammenarbeit
IDRC: International Development Research Centre
IITA: International Institute for Tropical Agriculture
LGA: Local Government Area
NASENI: National Agency for Science and Engineering Infrastructure
NIFFR: National Institute for Freshwater Fisheries Research
NGOs: Non-Governmental Organizations
NIHORT: National Horticultural Research Institute
NIMASA: Nigerian Maritime Administration and Safety Agency
NMR: Nuclear Magnetic Resonance
NWF: Natural Wildlife Federation
PH: Potential of Hydrogen
PLaWP: People, Land and Water Program
SE.EPPC: Southeast Exotic Pest Plant Council
TISI: Texas Invasive Species Institute
TSD: Total Dissolved Solids
TSS: Total Suspended Solids
UF/IFAS: University of Florida/Institute of Food and Agricultural Sciences
UNEP: United Nations Environment Programme
USA: United States of America
USAID: United States Agency for International Development
USDA: United States Department of Agriculture
USD: United States Dollar
USFWS: United States Fish and Wildlife Services
USGS: United States Geological Survey
WH:  Water Hyacinth
CHAPTER ONE
INTRODUCTION

The oceans and seas cover more than 70% of the surface of the Earth, and are the reason for it being called ‘the blue planet’. The oceans and seas feed humans, regulate the climate, and produce more than half of the oxygen on the earth’s surface (see Figure 1). They are also useful in supporting and promoting the economy of the world, creating opportunities for tourism, fisheries as well as enhancing international shipping and world trade (UNEP, n.d).


Furthermore, the total freshwater of the Earth is made up of rivers (0.025%) and lakes (less than 0.5%) (Lawrence, Dale, George, and Stanley, 2019) as well as streams and creeks, which are very useful for the Earth’s lifeform making up a significant part of
the water cycle of the Earth (USGS, 2019). These freshwater resources, however, are under threat due to pollution, climate change, water-related diseases, degradation and destruction of freshwater ecosystem and overexploitation of resources due to human activities (Gleick, Singh & Shi, 2001).

Additionally, wildlife also faces threats from invasive species. About 42% of species are endangered as a result of threats from invasive species. Invasive species may also constitute a risk to the health of humans as well as to the world economy since agricultural, recreational and commercial activities largely depend on a natural and healthy ecosystem (NWF, n.d).

Similarly, aquatic ecosystems are primarily formed from aquatic plants, which convert the sun incident radiation energy to chemical energy. This is accomplished by converting carbon dioxide and water, alongside with nitrogen, iron, zinc, phosphorus, manganese, and molybdenum to biomass during photosynthesis. The first element that makes up the food chain in an aquatic ecosystem usually consisting of plant organism, which feeds animal organisms, invertebrates, finfish and shellfish (Oyedeji & Abowei, 2012). Aquatic plants can sometimes be reproduced from plant fragments and can constitute aquatic weeds which become invasive, thereby displacing native species. This can cause both environmental and socio-economic issues. In various areas around the world, the plant water hyacinth (see Figure 2) (*Eichhornia Crassipes*), which grows in freshwater ecosystems is regarded as a harmful weed with the tendency to grow swiftly by reducing the oxygen content and nutrients from freshwater ecosystems. The spread of the water hyacinth inversely alters the growth of other plants and animals in these water bodies (Sindhu, Binod, Pandey, Madhavan, Alphonsa, Vivek & Faraco, 2017). The water hyacinth was first discovered in South America and was first recorded in 1816. Its introduction was recorded in 1884 in New Orleans, Louisiana, the United States at a “Cotton States Exposition”, expanding through the south-eastern part of the U.S, and in 1895 it was found in Florida and 1904 in California (SE.EPPC, n.d).

The water hyacinth was introduced in several countries around the late 19th century as a decorative plant for cultivation in gardens and ponds; it then extended into...
freshwater ecosystems and lakes. During the 20th century, water hyacinth infestation was recorded in the tropics as well as in the subtropics and regarded as a highly troublesome aquatic weed throughout North America, Central America, Asia, New Zealand, India and Africa (Anuja, Neeraj, Saini & Yadav, 2016).

The water hyacinth is an aquatic floating flowering plant (perennial) with spongy tissue. It is highly adaptive and fast-growing, especially in warm climates and is highly invasive. It contains a high proportion of water in its cells. It hinders navigation and can be used as feeds for animals. The water hyacinth grows effectively and rapidly in water with low and high nutrient concentrations and doubles on the surface of freshwater every 4-7 days (Luis & George, 2000).

The water hyacinth grows vertically with large blades and elongated floats. It has fibrous roots of about 1mm in diameter and their length may vary from 200mm to 2,000mm depending on nutrient abundance (Yan & Guo, 2017). The root surface area of the water hyacinth (WH) is between 30mm to 60mm per single macrophyte (Yan & Guo, 2017). Because of its nature, spread and growth of infestation, WH is regarded as a noxious weed which invades rivers, lakes, agricultural fields, canals and ponds (FAO, n.d).

Around the early 1950s, the water hyacinth began infesting the freshwater ecosystem in Africa at an enormous scale (FAO, n.d). The borders of several countries in Africa and the Middle East have been infested with WH, and this plant is causing a severe problem already (Luis & George, 2000).

The water Hyacinth infestation has been recorded at different periods in most countries of West Africa; however, its invasion was more during the early 80s. It was first seen in 1957 in the Republic of Congo. The water hyacinth was first sighted along Ouémé River, Benin between 1980-1981 and in 1985, it increased exponentially; however, according to certain records, The WH plant was noted in Benin around 1977. In 1984, it was noted first in Ghana (Tema) and in Nigeria (a creek around Badagry). In 1991, it was noted in the Volta River in Burkina Faso, and in Mali around the 90s and between 1990-1994 in Niger (Luis & George, 2000).
The WH plant was sighted in Egypt during the later part of the 80s but became a water resource problem in 1932 and between 1975-1985, it was regarded as a noxious weed. WH was first sighted around 1910 in South Africa and was declared a noxious weed in 1983 by the “Conservation of Agriculture Act” through the Water Affairs Department. For more than four decades, WH has been recorded both in the southern and eastern Africa and since 1937 in Zimbabwe. WH kept on infesting major bodies of water like the River Incomati in 1946 Mozambique, the River Zambezi Ethiopia in 1956, in the late 50s, WH infested rivers in both Rwanda and Burundi. In Tanzania, it infested river Pangani in the 60s and also infested river Kafue in Zambia within the same period; WH infested River Shire in Malawi during 1968, and the Naivasha lake in Kenya between 1982–1983. WH also infested Kyoga lake between 1988 and 1989 in Uganda, Lake Victoria between 1989 and 1990, Malawi-Nyasa was infested in 1996, and Tanganyika infestation in 1997 (Luis & George, 2000).

The water hyacinth was first sighted in Nigeria around the Badagry Creek in Lagos where it covered the surface area of the creek in September 1984, and by the year 1990, it had covered the whole coastline in the lagoon and creeks of Nigeria as well as inland waters. The water hyacinth also spread to the River Niger, River Benue, Kaduna River, the Benin River, several lakes, large reservoirs and dams such as the Kainji dam (Bolorunduro, 2002).
1.1 Problem Statement

The water hyacinth is alien to the Nigerian water ecosystem. It was introduced as an ornamental plant which later became a weed as a result of high levels of nutrients from urban municipal and industrial wastewater (Baret & Farno, 1982). The water hyacinth was first seen in 1984 (Akinyemiju, 1987) along Badagry creek Lagos State Nigeria and by 1992 it was noticed in the River Niger and Kainji lake. It came from the Niger Republic at Lolo (Kusemiju & Chizea, 1992) posing a serious and significant threat to the Kainji dam, which supplies hydro-electricity to Nigeria and the Niger Republic. The water hyacinth has spread to the coastlines of Nigeria from the Southwest, the Southeast to the Southernmost areas and has infested 20 of the 36 States as well as Abuja the Federal Capital Territory (NIFF, 2000). The water hyacinth covers 1,000 to 2,000 hectares of Lagos Lagoon (NIFF, 2002; Wilson et al., 2007) and millions of tonnes of new water hyacinth grow each year creating a menace to water safety in Lagos especially the Ajah area, Lagos Islands, Ikorodu, Badagry, Oworonshoki, Mile
2 and Epe. They cause problems for boat propulsion systems limiting water transportation activities (Ships and Ports, 2016). It also prevents swimming and keeps sunlight from reaching the water column, thus disrupting photosynthesis in other aquatic plants.

The water hyacinth alters the ecology of freshwater and affects the environmental, sociological, cultural and economic heritage of millions of people living in communities along the coast especially the artisanal fisher population (Uka, Chukwuka & Daddy, 2007). More than 12,000 hectares of the Delta area of Nigeria comprising rivers, lakes and creeks have been infested with the water hyacinth, affecting the livelihood of over 40 million people in Nigeria (Ndinwa, Dittimi & Akpafun, 2012) and leading to diseases such as bilharzia.

The water hyacinth infestation in Nigeria poses severe problems to the fishing and transportation industries (Uka, Chukwuka & Daddy, 2007) by clogging major waterways and creating associated problems with water supply, irrigation and drainage. It also prevents navigation of boats and other vessels and threatens the generation of hydro-electricity; an example is the infestation of the Kainji lake which hampers the activity of the Kainji dam. Furthermore, it reduces the availability of freshwater by increasing evapotranspiration and reduces water quality through the introduction of particulate matter, thereby producing an obnoxious odour. The dense growth of the water hyacinth disrupts aquatic life, fish and phytoplankton and causes siltation as well as the gradual drying up of water bodies (Kusemiju, 2002).

1.2 Objectives of the Study:
- To identify the origin of the water hyacinth in Nigerian inland waters.
- To determine the mode of adaptation of the water hyacinth in freshwater ecosystems in Nigeria.
- To discover the growth mechanism for the spread of the water hyacinth in Nigerian inland waters.
- To identify the effects of the water hyacinth infestation in the coastal regions of Nigeria.
To assess the various uses of the water hyacinth.
- To provide the most viable method for the control and management of the water hyacinth.

1.3 Historical Background of Nigeria:
Nigeria, (see Figure 3) is located in West Africa. The British Protectorate merged the northern and southern part of Nigeria in 1914 and got its independence on 1st October 1960. Nigeria adopted a republican constitution in 1963 (Anthony, Toyin, Ajayi & Reuben, 2019).


Nigeria is made up of more than 250 ethnic groups, endowed with different cultural heritage. The position of Nigeria is situated towards the farthest part of the Gulf of Guinea to the west of Africa, which lies in an interval of “latitudes 3°15’ - 13°30’ N
and longitudes $2^\circ59' - 15^\circ00' E$”. Nigeria has a boundary with the Gulf of Guinea to the south, the Republic of Benin to the west, the Republic of Niger to the north and bordered to the Republic of Cameroon to the east (FRN, 2016).

The total land area of Nigeria is about 923,768 km$^2$. The landmass is 910,768 km$^2$ and 13,000 km$^2$ is covered by water bodies. The distance between the North and South of Nigeria is 1,046 km, the breadth between East to West is 1,127 km, a boundary length of 4,900 km, and a coastline of 853 km. The GDP of Nigeria between 2005 and 2014 was more than 500 billion USD and grew more than 7% annually, but slowed in 2015. Since 2013, Nigeria’s Foreign Direct Investment (FDI) is valued at 2 billion USD and has a GDP of 14% from the oil sector (FRN, 2016).

Nigeria has a tropical climate high in humidity and temperatures with marked wet and dry seasons with annual rainfall between 1,500 to 4,000mm in the south and 500 to 1,000 mm in the north. Nigeria has a vast inland freshwater ecosystem which spread throughout the country from the coastal regions to the Lake Chad Basin (FAO, n.d). It has a significant mangrove growth in the Niger Delta, River state, Cross River, Akwa-Ibom, Ondo and Lagos State. It lies between $3^\circ$ and $7^\circ$ N and covers between 500,000 and 885,000 hectares. The major rivers cover an area of about 853,600 hectares making up 11.5% of the total surface is of Nigeria. The extent of the major inland waters is shown in Figure 4. Thirteen lakes and reservoirs with an area of 4,000 hectares and 550,000 hectares cover a total surface area of 853,000 hectares. Deltas, estuaries, and saline wetlands cover a total surface area of 858,000 hectares, freshwaters cover about 3,221,500 hectares (FAO, n.d). These water bodies are connected and are used for fishing and for the transportation of goods and people, but the water hyacinth has taken over almost all areas of the freshwater ecosystem in Nigeria posing serious challenges, hence the need for this research.
1.4 Study Area

Mbat-Abiati Creek is located in Abiati village with Latitude 5°05’N to 5°06’N and longitude 8°27’E to 8°29’E. This creek is part of Akamkpa Local Government Area in Cross River State, southeast Nigeria. This creek is in the territory of the Great Kwa River in the Oban Hills of eastern Nigeria. The Great Kwa River is between latitude “4° 45’N and longitudes 8° 20’E” flowing southwards through the Cross River Estuary and made up semi-diurnal tides and vast mudflats (Bassey, Ifedayo & Ugbaja, 2018).

The surface waters in Mbat-Abiati Creek, which are surrounded and linked to other communities by a river is covered to about 60 – 70% of water hyacinth covers The primary mode of transportation in this creek is by boats and canoes. The surrounding area of the creek is made up of villages and farmlands which is approachable by foot (Bassey, Ifedayo & Ugbaja, 2018).
The study area is made up of tropical climate with dry and wet seasons. It is characterized by warm temperatures between 26 °C - 32 °C, annual mean rainfall of about 2300 mm, a yearly mean relative humidity/evaporation of 76 – 86% and 3.85 mm per day. The topography of the study area is characterized by plains of 200m above sea level made up of a moist forest with evergreen vegetation comprising shrubs, herbs and trees. The area is also made up of sedimentary rock deposits of a cretaceous nature such as limestones, shales, sandstones and marlstones (the Mfamosing Limestone Formation) (Bassey, Ifedayo & Ugbaja, 2018).

1.5 Literature Review:

According to Jonathan, (2017, p.1),

The water hyacinth mainly reproduces through stolons. This adaptation allows for a single plant to produce approximately 3,000 new plants in as little as 50 days or covers 600 square meters in as little as a year. Also, the water hyacinth seeds are adapted to be dispersed by birds and can remain viable for up to 20 years. The water hyacinth has other adaptations that allow it to grow and spread rapidly in freshwater. Its swollen leaf stalks are hollow and filled with air, and this allows it to be the only large aquatic herb that floats unattached from the bottom of its water source. The roots remain underwater in a thick mat, allowing the plant to obtain enough sunlight for photosynthetic processes. They are also adapted to withstand extreme temperatures, high pH levels and even toxic water. They are best grown in still or slow-moving water.

The rapid proliferation of the water hyacinth in Nigeria is attributed to pollutants in the water from petroleum industries, agricultural chemicals and minerals from erosion. The quantity of water hyacinth in the freshwater regions of Nigeria is due to unprecedented discharges of substances into these water bodies, thus increasing the nutrient availability. This leads to continuous increase and proliferation of water hyacinth in the Niger Delta regions of Nigeria (Ndinwa, Dittimi & Akpafun, 2012).
According to Bolorunduro (2002), the water hyacinth infestation clogs major waterways which creates navigational problems, disrupts water supplies, hinders national security, threatens hydroelectricity production, limits fishable waters and distorts irrigation and drainage patterns. Due to its growth and rapid spread, it is referred to as the “Blue Devil or Bengal Terror in India, Florida Devil in South Africa, German Weed in Bangladesh and Water Terror by fishing communities in the creeks and lagoons of south-western Nigeria”. The report indicated that the water hyacinth has spread to the Benue River system, River Niger, Benin River, Kaduna River, natural lakes and large dams as well as reservoirs like lake Kainji. This is seen as a major environmental problem.

Ndinwa, Dittimi and Akpafun, (2012), outlined three effective integrated methods in water hyacinth management and control. The biological, physical and chemical control methods.

A. The biological method of control is when a biological agent like insects or fungi is introduced to contain the infestation of the water hyacinth. Biological control methods are long term sustainable solutions to the management of the water hyacinth, but the insects have the potential to affect other components of the aquatic ecosystem.

B. The physical control method, which is a short-term control measure, involves the process of harvesting and on-site cutting of the water hyacinth with the use of mechanical equipment such as mowers, dredgers or weed harvesters specially designed for that purpose. This method causes fatigue when the on-site cutting method is used.

C. The chemical control method involves the use of herbicides (Glyphosate roundup, Diquat, and 2, 4-D amine and Dalapone) which are applied to control water infestation over large areas in a short time period. This method is less labour-intensive. Herbicides become expensive when used repeatedly to control the spread of water hyacinth, deoxygenation of water bodies can occur when spraying water hyacinth repeatedly with herbicides.
over a short time span and the herbicides can kill non-targeted aquatic plants.

According to Martinez (2003), identifying the growth cycle periods of the water hyacinth can aid in its management and control since flowering in aquatic macrophytes reduces the production of biomass and ramet. It has been observed that non-flowering plants produce more ramet and biomass than flowering plants. This event of the sexual reproductive cycle of aquatic macrophytes should be noted as the control point when control measures are applied.

Ogunlade (2002) on his notes on water hyacinth utilization outlined some beneficial uses of the invasive aquatic plant, such as.
- It can be used as animal and fish feed which has proven to be a good source of protein.
- The water hyacinth serves as a good source of raw materials for paper and board manufacture.
- It can be used to produce biogas which is an ideal clean energy source for electricity generation and for cooking.
- It can also be used for the manufacture of fertilizer as the root extract aids in crop production in a number of species such as Corchorus Capsularcas.
- Active Carbon from the water hyacinth, when combined with Zinc Chloride (ZnCl2), is suitable for decolonization use in pharmaceutical industries and for general application.

Ukiwe and Chukwuka (2007) reported that the Commonwealth Science Council of Malaysia is optimistic about the possible use of the water hyacinth as a means of pollution control in Malaysia. A wastewater investigation was done on the pig farming, electroplating, palm oil and rubber processing industries in Malaysia. The results showed that the water hyacinth is an economically viable option in the advanced treatment of palm oil mill and rubber factory effluent, which is a source of pollution in Malaysia and Nigeria.
Ndimele, Kumolu-Johnson and Anetekhai, (2011), in the Research and Journal of Environmental Sciences also outlined some uses of the water hyacinth, which are listed as follows:

- The water hyacinth can produce fibre boards which are used for low cost roofing as well as for indoor partitioning walls and ceilings.
- The fibre from water hyacinth stems can be used to make ropes and when treated with sodium metabisulphite (to prevent it from rotting) is used for furniture production especially in Bangladesh.
- The water hyacinth stalk can be used to make baskets and mats for domestic use.
- There is a proposal in Kenya to develop a “technology for the briquetting of charcoal dust from the pyrolysis of water hyacinth”.
2.0 Introduction
Water hyacinth (*Eichhornia crassipes*) belongs to the Pontederiaceae, family, which is a freshwater aquatic perennial plant that grows freely floating in an erect position, with a length of 10 cm to 1 m in height and has a feathery black or purple root of 1 m in length immersed in water. They proliferate in waters that are rich in nutrients and have stems (stolons) which are horizontal and reproduce at the nodes to form new plants. The stem of the water hyacinth form a group of leaves, and the leaf stalk is spongy; it is usually inflated around 2.5-75 cm in length and 3 cm in diameter (AUG, n.d).

WH leaf is flat, circular, rectangular and thick; it is about 15 cm to 25 cm wide. The stalk bearing the flower is about 50 cm long with a spike of 20 cm in length. WH flowers are 3-7 cm wide with six petals (3 to 5 cm in length) fused at the base and the leaves have blue, bluish-purple, mauve, violet and often white in colour. WH fruits have three-chamber bulbs of about 15 mm in length and about 1-1.5 mm long 300 seeds (AUG, n.d).

2.1 Characteristics of the Water Hyacinth
A fresh WH plant comprises moisture (95.5%), nitrogen (0.04%), ash (1.0%), P$_2$O$_5$ (0.06%), K$_2$O (0.20%) and organic matter (3.5%), when measured on a mass basis. Without moisture, “the WH plant contains nitrogen (1.5%), ash (24.2%) and organic matter (75.8%). WH ash has K$_2$O (28.7%), Na$_2$O (1.8%), CaO (12.8%), Cl (21.0%) and P$_2$O$_5$ (7.0%)”. WH crude protein using the Kjeldahl method (CP = amount of nitrogen × 6.25) per 100 g, methionine (0.72 g), phenylalanine (4.72 g), threonine (4.32 g), lysine (5.34 g), isoleucine (4.32 g), valine (0.27 g) and leucine 7.2 g (Rezania, Ponraj, Din, Songip, Sairan & Chelliapan, 2015)

2.2 Taxonomy
The plant WH has about seven species making up the genus *Eiccornia*, example of which is *E.Crassipes*, *E. Speciosa*, *E. Azurea*, and *E. Natans*. In Africa, the *E. Natans* and *E. Crassipes* species of WH are vast in quantity, and the *E. Crassipes* is the most common WH species found in the freshwater bodies of Nigeria. The leaves of *E. Crassipes* species are glossy with showy purple colour and inflated petioles. Its roots are confined to the substrate and mostly found in ponds that are shallow, and on the banks of lakes and rivers while the *E. Natans* roots, stems and leaves are submerged in water (Elenwo & Akankali, 2016). Table 1 shows the taxonomic classification of water hyacinth.

Table 1 Scientific classification of water hyacinth

<table>
<thead>
<tr>
<th>KINGDOM</th>
<th>PLANTAE</th>
<th>PLANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subkingdom</td>
<td>Tracheobionta</td>
<td>Vascular plants</td>
</tr>
<tr>
<td>Superdivision</td>
<td>Spermatophyta</td>
<td>Seed plants</td>
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<tr>
<td>Division</td>
<td>Magnoliophyta</td>
<td>Flowering plants</td>
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<tr>
<td>Class</td>
<td>Liliopsida</td>
<td>Monocotyledons</td>
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<td>Subclass</td>
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<td>Family</td>
<td>Pontederiaceae</td>
<td>Water hyacinth family</td>
</tr>
<tr>
<td>Genus</td>
<td>Eichhornia <em>Kunth</em></td>
<td>Water hyacinth</td>
</tr>
<tr>
<td>Species</td>
<td><em>Eichhornia crassipes</em> (<em>Mart.</em> <em>Solms</em>)</td>
<td>Common water hyacinth</td>
</tr>
</tbody>
</table>

2.3 Morphology

Depending on the growth factors of WH, WH exhibits two distinct intermediate morphologies. In waters with high nutrients free of herbivores, WH petioles in its relative density are 1m long with round leaves, which are less than 30 cm with a shape like a bulb and when the mats of WH infestation are less dense, the leaves are shaped like a kidney. This illustrates that both morphologies appear to demonstrate distinctive photosynthetic behaviour (EPPO, 2008).

The developed WH plant consists of fruit clusters, leaves, long pendant-like roots, rhizomes and stolons. The water hyacinth relative average height is about 40cm, which can grow to 1m in height. The flowers of the WH plant has a diameter of 4-7cm each and 6 to 10 flower leaves. The stems and leaves of WH also consist of tissues (air-filled), which makes it buoyant (Rezania, Ponraj, Talaiekhozani, Mohamad, Din, Taib & Sairan, 2015).

Figure 5. Morphology of water hyacinth plants (*Eichhornia Crassipes*)

2.4 Biology

The mats of WH can achieve significant biomass and density as an individual hectare have the potential to embody 360 tonnes of biomass or more. WH reproduces both sexually and asexually, thereby aiding the modes to proliferate. During moderate climates, WH flowers grow throughout the year and can generate sufficient seeds produce an abundance of seeds (FWS, 2015). In the tropics, WH generates more seeds than in the temperate regions due to increased pollination rates by insects. The seedlings of WH sprouts faster when the water levels are low in soils that are mostly saturated.

Population increase in WH plant is through ramet (daughter plant) vegetation from axillary buds (stolons) of elongated internodes. As the ramets develop roots, the axillary buds or stolons disintegrates and splits from the original plant. Under favourable conditions, these daughter plants through its spread, thus aid in the swift increase in WH population in an interval of 1 to 3 weeks (EPPO, 2008).

The WH plant produces fruits or seeds at a temperature of 22.5°C - 35°C and at a humidity of 90% and the growth of these seeds are influenced by a significant amount of light, and a changing high and low temperatures of 5°C - 40°C. If the plant is introduced in near-freezing temperature for 2 to 4 weeks, its population will be reduced greatly (FWS, 2015).

The leaves of WH display anatomical feature of various types of metabolism, usually not found in one plant (a C3 plant and exhibits a feature of a C4 plant in a photosynthetic process particularly when it is not affected by significant light levels).
These characteristics make it unusually potent, thus the growth level is recorded at 1.012 – 1.077 and can increase its biomass production to 12% daily or double between 6 – 15 days respectively. The productivity rate of WH is specified to 100 to 500g fresh weight/m2 daily or 1000 to 5000kg/ha and 400 to 1700t/ha yearly (CABI, 2018). The entire biomass of an erect WH plant can be up to 42kg/km2 or 420t fresh weight/ha while the dry weight is usually 5 to 7% of the fresh weight and this makes up 2.5kg dry weight/m2 or 25t dry matter/ha. The foliage of WH plant according to a study in Florida is hugely dense with 7.8 and 5.8 leaf area index values (CABI, 2018).

2.5 Ecology

The WH plant is regarded as a heliophyte plant, which grows in waters that are warm and abundant in macronutrients. The ideal pH for the growth of WH plant in any water body is neutral, though it can withstand a PH value of 4 -10 pH. This characteristic indicates that WH is very viable in treating wastewater of different composition (Jafari, 2010). The most desirable temperature for WH growth in any freshwater body is between 28 to 30° C, and temperatures beyond 33° C prevents more growth. The required ambient air temperature for favourable growth is 21 to 30° (Jafari, 2010). The leaves of WH plant is damaged when temperatures of -3° C last for more 12 hours and temperatures of -5° C damages the entire plant when it lasts for more than 48 hours. The WH plant can stay alive under temperatures of 0.5° to temperatures of -5° C and dies at temperatures of -6 to -7° C and can not grow in the open during winter when temperatures fall below 1° C. The growth of WH plant can also be affected by reduced air humidity of 15% - 40% and can withstand drought since it thrives well in sediments that are moist (Jafari, 2010). The main factor hindering the growth of WH is salinity as increased salinity affects the growth of WH by producing necroses on WH leaves (Jafari, 2010).

In an aquatic distribution channel, WH directly alters and slows the flow of water by 40 - 95%, which may lead to intense flooding which and may also affect the ecology of the natural system. Furthermore, it has been noted that the mats of WH reduce the temperature, alkalinity, pH, dissolved oxygen content and bicarbonate in freshwater
ecosystems. It also increases the levels of nutrients, as well as the free carbon dioxide content of water (Bhattacharya, Haldar & Chatterjee, 2014). Acidic and alkaline waters support the growth of WH but it does better in almost neutral bodies of water. Under ideal conditions, the WH plant has the potential to absorb two-thirds of the phosphorus and nitrogen content of wastewater and could completely alter an entire freshwater ecosystem (Bhattacharya, Haldar & Chatterjee, 2014).

2.6 Chemistry of Water Hyacinth

According to Ndimele, Kumolu-Johnson and Anetekhai, (2011), WH is made up of 90 per cent of water and approximately 15 to 20 per cent of solid matter, and the dry weight of WH is made up of approximately 25 to 35 per cent of protein matter, which is particularly amino acids (17%) and amides which is a toxic matter. Analysis displays that the dry WH plant contains a carbon content of approximately 36 to 40 per cent and the ratio yields of carbonates and nitrates obtained are about 40 to 60 per cent from direct carbonylation. Furthermore, WH has a primary cellulosic structure, which is infused “by the amino group” just at the carbonyl structure (Ndemele et al., 2011). This is shown in Figure 6.

![Figure 6. Water Hyacinth chemical structure: “R could be CH₂ or long-chain CH₂-CH₂”. Adapted from scialert.net by Ndemele et al. (2011). Retrieved from https://scialert.net/fulltextmobile/?doi=rjes.2011.509.520#7813_tr](https://scialert.net/fulltextmobile/?doi=rjes.2011.509.520#7813_tr)
R, according to research, is of the aliphatic chain and the chemical composition of WH is made up of approximately 12.8% nitrogen, carbon (36-40%), 8% hydrogen and 13 to 14% oxygen. WH is used for phytoremediation and has been noted to convey heavy metals such as magnesium, zinc and iron. It also contains traces of calcium and phosphorus, referred to as metallic ligands (Ndimele et al., 2011). Istirokathoun et al (2014) describe dry WH as consisting of 25 % cellulose, 33 % hemicellulose, and 10 % lignin.

2.7 Habitat
The plant WH is mostly found in a vast diversity of aquatic and wetland ecosystems such as streams, lakes, ponds, backwater areas, waterways and ditches. WH gets its nutrients from these water bodies and from wastewater treatment facilities. Parent plants through its daughter plants form new growth of WH plant, and water current and the action of wind aid in its vast distribution (AERF, 2005). WH can endure extreme fluctuating water levels, flow levels, declined nutrient levels and acidity (TISI, 2014).

2.8 Geographical Distribution
The German naturalist Martius Von discovered WH in 1823 in Brazil, and it is presently found along the tropical and subtropical area around 39°N and 39°S (Tellez et al. 2008). Since its discovery, humans have been responsible for its spread to Asia, North America and Australia. WH was first sighted in the United States during the 1880s. In South America, it was sighted in Brazil in 1902, Argentina in 1942, Paraguay, Uruguay, Bolivia, Ecuador in, and Colombia 1959, Venezuela 1976, and Chile in 1979 (Tellez et al., 2008). In central America, WH was discovered in Costa Rica, Nicaragua, El Salvador and Mexico in 1965, Panama 1966, Dominican Republic and Puerto Rico in 1971. The spread of WH has been discovered in various areas of Africa in the tropical and sub-tropical area. It is believed that the plant came through Sudan into the Congo River and expanded through the aid of floods (Tellez et al., 2008) and became a problem in the continent in the 40s. In Asia, WH was introduced
through Indonesia and Japan during the end of the 19th century. WH as of today stretches from the plains towards an altitude of 1600m. It was discovered in Bengal India in 1890 and could be found in almost all parts of the country. It was discovered in Taiwan and China mainland and sighted in Oceania and Australia in 1890 and in several islands in the Pacific Oceans (Tellez et al., 2008). WH entered Europe through Portugal around 1939 and has expanded over the west-central part of the country. It found its way into the Tagus and lower Sado Basins in the middle of the country through irrigation channels. It was noted in Spain between parallels 36° and 43°N (Tellez et al., 2008).

2.9 Distribution in Nigeria

The water hyacinth plant, which is currently distributed around the tropical and subtropical geographical regions of the world was sighted in Nigerian water bodies at the shore of Lagos lagoon around the Badagry Creek in 1984 through the Port Novo. By 1992, it had spread to River Niger and the Kainji Lake. (Ojeifo, Ekokotu, Olele& Ekelemu, 2002). This noxious aquatic weed is vastly distributed around the coastal states of Nigeria (Uka, Mohammed & Ovie, 2009). The spatial distribution of WH in Nigeria is illustrated in Table 2.
Table 2: Qualitative rating of level of water hyacinth and other aquatic weeds infestation in Nigeria.

<table>
<thead>
<tr>
<th>State</th>
<th>Type of weeds</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Niger</td>
<td>+++</td>
<td>Water hyacinth is commonly sighted throughout the year on Lake Kainji &amp; Jebba Lakes covering up to 2% and 15%, respectively.</td>
</tr>
<tr>
<td>FCT, Abuja</td>
<td>++</td>
<td>Water hyacinth occurs within Yaba flood plain covering up to 5%</td>
</tr>
<tr>
<td>Kaduna</td>
<td>++</td>
<td>Water hyacinth is sighted on River Kaduna</td>
</tr>
<tr>
<td>Plateau</td>
<td>+</td>
<td>Water hyacinth sighted in Hill Station Hotel.</td>
</tr>
<tr>
<td>Nassarawa</td>
<td>++</td>
<td>No water hyacinth infestation in the State.</td>
</tr>
<tr>
<td>Benue</td>
<td>+++</td>
<td>Water hyacinth occurs along the beaches and mats adrift downstream</td>
</tr>
<tr>
<td>Kogi</td>
<td>+++</td>
<td>Both Rivers Niger &amp; Benue are infested with water hyacinth including the wetlands.</td>
</tr>
<tr>
<td>Kwara</td>
<td>+++</td>
<td>Rivers, Niger, Asa, Awon, Oshin, Afelele and Jebba lake are water hyacinth infested.</td>
</tr>
<tr>
<td>Adamawa</td>
<td>+++</td>
<td>Lake Oeriyo and River Benue is infested with water hyacinth and Pistia sp. flood plain at Numari is covered by Typha australis.</td>
</tr>
<tr>
<td>Borno</td>
<td>+++</td>
<td>Lake Chad is heavily infested with Pistia stratiotes while Lake Alau is mildly infested.</td>
</tr>
<tr>
<td>Gombe</td>
<td>++</td>
<td>Typha grass occurs along most irrigation canals</td>
</tr>
<tr>
<td>Taraba</td>
<td>+++</td>
<td>Water hyacinth occurs along River Benue from Numari to Lobi</td>
</tr>
<tr>
<td>Bauchi</td>
<td>+</td>
<td>Lake Oubi has mostly Pistia and water lily. Cattail occurs sparingly in some drainage canals below the lake.</td>
</tr>
<tr>
<td>Yobe</td>
<td>+</td>
<td>Major water weeds are cattail and water lettuce. Cattail is mostly along irrigation canals. Damming of River Yobe at Bauchi is envisaged to reduce flow of water to the irrigation canals.</td>
</tr>
<tr>
<td>Kebbi</td>
<td>+++</td>
<td>Water hyacinth is very prominent especially in River Niger. The floods also bring in the weed into Rivers within the Sokoto-Rima catchment</td>
</tr>
<tr>
<td>Sokoto</td>
<td>++</td>
<td>The problematic weed is cattail, that has overtaken a lot of water bodies. Water hyacinth is present in only one fish farm. Although efforts are on to clear it, releases of water from this fish farm could lead to infestation of other water bodies.</td>
</tr>
<tr>
<td>Zamafara</td>
<td>+</td>
<td>The most important weed problem is caused by invasion of water bodies by cattail.</td>
</tr>
<tr>
<td>Katsina</td>
<td>+</td>
<td>Cattail constitutes the major weed problem of water bodies and water ways</td>
</tr>
</tbody>
</table>

*EC = Eichhornia crassipes; PS = Pistia stratiotes; NL = Nymphaea lotus; Ta = Typha australis; OT = Other Weeds*

<table>
<thead>
<tr>
<th>State</th>
<th>EC</th>
<th>PS</th>
<th>NL</th>
<th>TA</th>
<th>OT</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kano</td>
<td>+++</td>
<td>++</td>
<td>++</td>
<td>+++</td>
<td></td>
<td>Water hyacinth infestation of a good number of water bodies was significant. However, Cattail still constitutes the major weed problem.</td>
</tr>
<tr>
<td>Jigawa</td>
<td>_</td>
<td>++</td>
<td>++</td>
<td>+++</td>
<td></td>
<td>The water bodies and irrigation systems have been overtaken by extensive invasions of cattail. The problem of this weed is of a great magnitude</td>
</tr>
<tr>
<td>Delta</td>
<td>++++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td></td>
<td>Water hyacinth problem is significant and the major weeds are present including cattail.</td>
</tr>
<tr>
<td>Edo</td>
<td>++++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td></td>
<td>There is the presence of water hyacinth as a major weed problem. Cattail is not present.</td>
</tr>
<tr>
<td>Osun</td>
<td>++</td>
<td>_</td>
<td>++</td>
<td>+++</td>
<td></td>
<td>Water hyacinth is present in a few water bodies</td>
</tr>
<tr>
<td>Ondo</td>
<td>++++</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td></td>
<td>Water hyacinth infestation of water ways is frequent but the intensity is high in only a few water bodies.</td>
</tr>
<tr>
<td>Ekiti</td>
<td>++++</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td></td>
<td>The situation here is that a few water bodies are heavily infested by Water hyacinth</td>
</tr>
<tr>
<td>Oyo</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>+++</td>
<td>+</td>
<td>Infestation of water bodies by water hyacinth and even other weeds is low, but the presence of cattail is important.</td>
</tr>
<tr>
<td>Ogun</td>
<td>++++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td></td>
<td>A good number of water bodies are infested by Water Hyacinth to significant levels.</td>
</tr>
<tr>
<td>Lagos</td>
<td>++++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td></td>
<td>A lot of water bodies are heavily infested by water hyacinth</td>
</tr>
<tr>
<td>Anambra</td>
<td>++++</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td></td>
<td>Moderate levels of infestation plague water bodies in this State by Water Hyacinth and other weeds.</td>
</tr>
<tr>
<td>Enugu</td>
<td>_</td>
<td>++</td>
<td>+</td>
<td></td>
<td></td>
<td>This State is largely free from water hyacinth and other aquatic weed problems.</td>
</tr>
<tr>
<td>Ebonyi</td>
<td>++++</td>
<td>++</td>
<td>++</td>
<td></td>
<td></td>
<td>Water hyacinth is absent so also is cattail.</td>
</tr>
<tr>
<td>Abia</td>
<td>++++</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
<td></td>
<td>The State's water bodies are moderately infested by water hyacinth. The frequency of infestation is high. Water hyacinth is present.</td>
</tr>
<tr>
<td>Imo</td>
<td>++++</td>
<td>++</td>
<td>++</td>
<td></td>
<td></td>
<td>Water bodies in this State are moderately infested by Water hyacinth and other water weeds.</td>
</tr>
<tr>
<td>C/River</td>
<td>++</td>
<td>+++</td>
<td>++</td>
<td></td>
<td></td>
<td>Water hyacinth is present in major water bodies of the State of noticeable levels</td>
</tr>
<tr>
<td>Akwa-</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td></td>
<td></td>
<td>Prominent water bodies of this State are infested to nuisance levels by Typha spp. However, water hyacinth is absent.</td>
</tr>
<tr>
<td>Illitom</td>
<td>++++</td>
<td>++</td>
<td>++</td>
<td></td>
<td></td>
<td>Records of visible presence of Water Hyacinth in major water bodies exist.</td>
</tr>
<tr>
<td>Rivers</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td></td>
<td></td>
<td>Both Water hyacinth and Typha spp. are visibly present in the water bodies.</td>
</tr>
</tbody>
</table>

KEY: - = Absent; + = Rare; ++ = Slight; +++ = Moderate; ++++ = Extensive

*EC = Eichhornia crassipes; PS = Pistia stratiotes; NL = Nymphaea lotus; TA = Typha australis; OT = Other weeds
2.10 Elements Controlling the Growth and Spread of Water Hyacinth in Nigeria

The growth and distribution of aquatic weeds such as WH in Nigeria are generally controlled by the activities of humans like environmental alteration, increased use of water for recreation, transportation and irrigation. A summary of other factors is outlined below.

Salinity Tolerance

The water hyacinth according to research cannot withstand salinity in freshwater bodies. The salinity of most rivers in the coastal states of Nigeria is profoundly reduced during the raining season, which contributes to the growth and spread of WH during this season (Akinyemeju, 1987).

Temperature

Changes in temperature as a result of the natural duration in daylight and incident solar radiation occur mostly in the majority of water ecosystems. It is generally known that temperature and light coherently affect the distribution, growth, photosynthesis morphology, chlorophyll composition, and reproduction of macroscopic aquatic plants (Barko, Adams & Clesceri, 1986). The distribution of aquatic macrophytes has been altered by the physiology of the surrounding temperature of water and sediment as well as seed germination, the period of dormancy and the season of growth (Lacoul & Freedman, 2006).

Nutrient Enrichment

The proliferation of macroscopic plants in the freshwater ecosystems, according to research, has been mainly attributed to nutrient enrichment, especially nitrate and phosphate, this has been observed to aid the growth of these aquatic macrophytes. Nutrient enrichment may lead to extreme alteration in density, and composition of species richness in lakes and other water bodies (Dar, Pandit & Ganai, 2014).
Nutrient accumulation in rivers, streams and lakes has been associated with land use by humans and population density. The accumulation of nutrients within the aquatic environment as a result of human activities originates from industrial and municipal wastewater effluent, storm sewer discharge, crop fertilisers, livestock farming and urban runoff (Eruola, Ojekunle, Amori, Awomeso, Amole, & Anthony, 2015).

Wind and Waves
Wind and waves can have both beneficial and detrimental outcome on aquatic macrophytes based on their intensity and rate of occurrence. Wind and wave actions influence the pollination, the dispersal of daughter plants, the cycling of nutrients, and the uprooting of aquatic plants. Wave level and direction expose aquatic plants at the intertidal zone, which is controlled by force of attraction, wind duration and speed. Habitats with severe wind and wave actions will uproot and damage matured aquatic plants (Lacoul & Freedman, 2006), and thereby reduce the occurrence of the water hyacinth.

2.11 Impact of Water Hyacinth Infestation in Nigeria
The infestation of WH, an aquatic plant, a macrophyte poses serious impact in riparian and coastal communities in Nigeria. This noxious aquatic weed blocks water channels along creeks by preventing boat transportation, fishing activities, creates health implications, creates a dwelling place for disease vectors and increase the loss of wetlands at an alarming rate (FAOb n.d). The problems caused by WH are illustrated below.

Impact on Water Transport
In Nigeria, the WH has been known to block waterways and hamper navigation, affect boats by leading to the damage of hulls as they collide with objects under WH marts. WH mats prevent means of approaching harbours and jetties as well as clodding rivers and canals. WH is becoming a problem as it also prevents the passage of marine vessels (Ndinwa, Dittimi & Akpafun, 2012). Within the Delta region of Nigeria, operations of several boat harbours and maritime workers have been limited as the aquatic plant
blocks facilities and damages boat ramps causing overheating in boat motors. WH decreases the use of facilities for boat rentals and other maritime businesses (Ndinwa et al. 2012).

**Impact on Fishing**

Water hyacinth infestation according to fishermen in the northcentral Nigeria is one of the major obstacles to the development of fishing in the area. The two major rivers in Nigeria: River Niger and River. ???, as well as their tributaries, provide fishing opportunities for the people of northcentral area and River Niger, its confluences and tributaries pass through seven states (Kebbi, Niger, Kwara, Kogi, Edo, Delta and Anambra). The River Niger is solely responsible for domestic production of fish in Nigeria. It accounts for about 49.8% - 97.7% of fish production with an annual average of 86% from 1970 to 2014 (Oladimeji, Abdulsalam, Muhammed-Lawal, Adefalu & Adepoju, 2016) Therefore, fishing production between 2008 - 2012 contributed 3.5 – 4% of the total GDP in Nigeria (10% of agricultural GDP). However, water hyacinth infestation in the area prevents access to the river, hampering fishing activities, reducing water transport as well as creating difficulty in navigation. This leads to the reduction of fish catch particularly mudfish and tilapia found along the shores and eventually leads to the loss of livelihood (Oladimeji et al. 2014).

In the Delta regions of Nigeria, WH obstructs access to fish landing areas, alters fish breeding sites, reduces species diversity, thereby leading to poor quality of fish, decreasing fish production, increasing operation cost and subsequently reducing incomes of fishers (Ndinwa et al. 2012).

**Impact on Hydropower**

Several hydropower systems in the world have been affected by the infestation of WH in the lakes that supply them. It hinders the generation of hydroelectric power as it limits the capacity of reservoirs to store water through the displacement of vast water volumes (Kusemiju, Farri, Chizea, & Ekere, 2002). Investigation shows that the water hyacinth has infested the Kainji Lake which covers the surface area of about 1250 km2 (Kusemiju et al. 2002). The infestation of the Kainji Lake by the WH plant is an indication of a serious problem to the Kainji Dam that furnishes Nigeria and the Niger Republic with hydroelectricity (Kusemiju, 2002).
The fast rate of reproduction in Kianji Lake slows down the waterfall even though infestation is relatively average; however, a shore part of the lake has been covered up to 19 meters apart extending towards the Kainji power station. The power station turbines are usually shut down at the dam to carry out the clean-up of the intake screens of the cooling system plug filter and the turbines. In order to keep the plants away from the turbines and to prevent them from causing damage and interrupt power supply, time and money are been employed to harvest the plants (Ndinwa et al. 2012).

**Impact on Water Quality**
As WH infests freshwater ecosystems, the growth of bacteria due to the decomposition process of the plant leads to elevated rates of biochemical oxygen demand (BOD). In the Delta area of Nigeria, rivers constitute a source of drinking water for the rural community, and as such BOD, which reduces water quality due to water hyacinth infestation affects this source (Ndinwa et al. 2012). Previous research on the effect of water hyacinth infestation on water quality was based primarily on the implication of the formation of thick mats of single interlocking WH plants, which leads to the reduction of productivity in phytoplankton and volumes of dissolved oxygen below mats (Perna & Burrows, 2005). The effect of WH infestation on water quality also leads to an increased rate of sedimentation in the intricate root structure of WH as well as increased rates of evapotranspiration from the leaves of WH compared to open water ((Ndinwa et al. 2012).
CHAPTER THREE
RESEARCH METHODOLOGY

3.0 Research design
Research design is the framework of research, which is made up of the most vital features and guidelines for planning data collection and data analysis. According to Inaam Akhtar, (2016, p. 68) “research design can be considered as the structure of the project together, in short, it is a plan of the proposed research work”.

This study uses a literature review, a questionnaire, and some experiments in order to gather data for analysis. The choice of the design is initially descriptive, and later uses in-depth analysis of the environmental and socio-economic impact of water hyacinth infestation in Nigeria. It evaluates the most viable means to control and manage its spread.

3.1 Methodology

3.1.1 Sources and analysis of literature data
A literature review and analysis of the data was conducted to obtain information about the uses of WH discussed in Chapter 4, and on the control methods applied to WH presented in Chapter 5. Secondary sources consist of government publications, research materials and other unclassified literature from archives and the Internet. The literature was analysed and evaluated with respect to socio-economic as well as environmental aspects. It was aimed to find economically viable, social and environmentally responsible solutions to the WH infestation problem.

3.2 Collection of Primary Data using Questionnaires
The research instrument used to collect the data presented in Chapter 6 (6.1. Regional approach) is a survey questionnaire. The questionnaire was designed, and a total of 30 questionnaires deployed to Mbat-Abbiati creek, to gather information in order to assess the impact of water hyacinth infestation in Nigeria inland waters. Primary sources were respondents from Mbat-Abbiati Creek, Abbiati Village in Akamkpa LGA, Cross River State, Nigeria. The Primary data was gathered with the help of a
The data was collected by an employee of NIMASA and filled out on-site by the local residents who occasionally asked some questions for clarification. Specifically, the questionnaire was designed to address the mode of spread, its harmful effect on water quality, vegetation, its utilization and its control. The targeted groups include fishers, transporters, farmers and the inhabitants of the creek. Out of the total questionnaires deployed, two (2) were filled out by the residents of the study area and returned. The reason for the low return rate was due to the fact that some members of the targeted groups went fishing and the rest were reluctant to give out information about their community mostly because of the lack of assistance from the government in managing WH infestation within the community. It was also difficult to access the creeks because of the heavy rains, which cut off the access routes. Therefore, additional resources and efforts may be necessary for higher returns of information in future work.

### 3.3 Testing of some Environmentally Acceptable Herbicides

An indoor experiment was conducted to determine the effectiveness of using environmentally acceptable herbicides like acetic acid, formic acid and citric acid to eradicate aquatic weed. The results of these basic experiments are presented in Chapter 5.

### 3.4 Study area

The study was conducted at Mbat-Abbiati Creek, Abiati Village in Akamkpa Local Government Area, Cross River State. The people of Abiati Village are predominately traders and fishers. The topography of the study area is characterized by plains of 200 m above sea level made up of a moist forest with evergreen vegetation comprising shrubs, herbs and trees. The area is also made up of sedimentary rock deposits of a cretaceous nature such as limestones, shales, sandstones and marlstones (the Mfamosing Limestone Formation) (Ephraim et al. 2018).
CHAPTER FOUR
UTILIZATION OF WATER HYACINTH

Even as the WH is regarded as the most troublesome aquatic weed throughout the world with the ability to negatively alter socio-economic and environmental factors, in some countries, its utilization provides income for the populace. The possibility of utilizing the water hyacinth plant has been identified from the published literature as follows:

4.0 Fish and Animal Feed

4.0.1 Fish Feed.
According to Akeem, Sotolu and Sule, (2010), WH has been noted to have a beneficial nutrient effect on the growth of fish. It can be used by fish farmers as a least-cost feed for the sustainable production of fish and has been shown to be an alternative source of protein. The meal from the water hyacinth leaves has been identified to be more sufficient and appropriate for the production of fish than the meal made from the whole plant.

After a laboratory experiment at the National Institute for Freshwater Fisheries Research (NIFFR) in Nigeria, (Okoye, Daddy & Jlesanmj, 2002) confirmed that water hyacinth leaves contain a higher value of 15.27% crude protein and the petioles as 7.11% low value of crude protein, by mass. Okoye et al. (2002) further established that WH leaves contain a low value of moisture, ash, crude, fibre, sodium and potassium. Water hyacinth roots contain a relatively low value of crude protein (6.67 %), crude fat and lipid with high ash and moisture content, which cannot be used as a supplement for fish feed. The entire WH plant has a high value in potassium and crude fibre (69 % highest value) without the roots.

4.0.2 Animal Feed

Su et al. (2018) outlined that the fresh biomass of WH plant contains a crude protein value of 2.38 %, crude fat (0.27 %), crude fibre (0.91 %) and nitrogen-free extract (3.7 %), by mass. Despite the above, the dry matter of WH has abounding nutrients of
which crude protein is 10-20 %, which can be used as both roughage and protein feed. Research has shown that WH leaves after they have been cut and dried have a crude protein value of 15.58 to 19.97 %, crude fat (1.33 % to 1.85 %), crude fibre (13.74 % to 11.04 %) and ash content (16.04 % to 14.97 %). According to Abdelhamid and Gabr, (1991) the dry mass of the WH plant contains 20 % of crude protein, making it an excellent forage for animals. The protein content of WH is 6-10 % greater than the protein from soybeans in terms of productivity.

4.1 Raw Material for the Industry

4.1.1 Fibre Board

According to (Bhawana and Tanushree, 2019), a demonstration was done by the “House and Building Research Institute in Dhaka” to use the fibre of the WH plant in producing fibre boards. A production plant was developed by the institution to produce fibreboards and bituminised board for the widespread use and material for low-cost roofing respectively.

4.1.2 Yarn and Rope

Jafari (2010) states that rope can be made from the fibre of WH stems after the stalk is cut into narrow and long pieces of strips, which exposes the fibre and dried for days. The procedure of using WH for making rope is related to jute rope making process. Sodium metabisulphite is then used to treat the rope to stop it from deteriorating. The rope from the WH plant is used in Bangladesh to make furniture.

4.1.3 Baskets

Baskets and matting can be made from the dried form of WH, which has been done for domestic purposes, in the Philippines. It is essential for WH stalks to be dried adequately in other to get the best out of the raw material. Traditional weaving skills for basket making have been used in India to produce baskets and matting for the tourist industry (Jafari, 2010).
4.2 Raw Material for the Production of Biogas

Biogas is regarded as an environmentally clean fuel made from the process of anaerobic digestion of natural waste like municipal solid waste, industrial waste, cow dung and vegetable waste (Njogu, Kinyua, Muthoni & Nemoto, 2015). The use of biogas for domestic and industrial purpose is becoming relevant as they are cost-effective and clean. Biogas is made up of nitrogen (N₂) (5-6 %), carbon dioxide (CO₂) (30-33 %), traces of hydrogen sulphide and methane (CH₄) (49-53 %). Due to high content of the carbon-nitrogen ratio in the water hyacinth, it is a potent feedstock for the biogas production as stated in Njogu et al. (2015) after an experiment to determine the potential use of WH for biogas production. The production of biogas requires the wet plants to be fermented in a digester for several weeks, in order to produce the biogas. The residual substance from the fermentation process can subsequently be used for the production of compost.

4.3 Raw Material for the Production of Ethanol

Ethanol made from biomass is a viable source for fuel energy, which can be used for transportation. The efficient production of ethanol is focused on the use of substrate for optimized processes. Ethanol has a quality of reducing pollutant emissions from vehicle exhaust (Ganguly, Chatterjee & Dey, 2012). It has a higher latent vaporization heat and higher octane number than petrol, which can be used to increase the specific power output and efficiency of engines. The use of various kinds of lignocellulosic materials for ethanol production is preferable over that of sugar or starch, since it is more widely available and doesn’t directly compete with food production. The water hyacinth was considered a lignocellulosic material for an experiment as described in Ganguly et al. (2012), where the portions of cellulose in the WH plant were converted into bioethanol through the process of hydrolysis and fermentation of glucose sugar using enzyme hydrolysis. It was discovered that cellulose (1 kg) yielded 1.1 kg of glucose and 1 kg of cellulose yielded ethanol (0.56 kg). Istirokathoun et al. (2014) quoted dried WH as consisting of 25 % cellulose, 33 % hemicellulose, and 10 % lignin.
This means that every kg of dried WH could yield 140 g of ethanol if the cellulose alone were used for ethanol production.

4.4 Raw Material for Liquid Oil
Singh, Prakash and Bhaskar (2015) carried out a hydrothermal liquefaction experiment to convert the WH plant into a liquid oil product. These hydrocarbons could be used as fuels for ships, or refined to yield transportation fuels for aircraft or road vehicles. The hydrothermal liquefaction of the WH was performed under different thermal temperatures (250 to 300 °C) with residence times (15 to 60 min) and catalytic conditions (KOH and K₂CO₃). The use of alkaline catalyst greatly enhanced bio-oil yield. A maximum yield of bio-oil (23 wt%) was achieved, having 89% conversion rate of the water hyacinth. This oil was made up of two types of bio-oils, ‘bio-oil1’ and ‘bio-oil2’, which used diethylether and acetone as solvents for extraction and 1 N KOH solution as catalyst. Bio-oil1 and bio-oil2 showed having increased aliphatic content of carbon using H NMR and C NMR data. The results show that hydrogen and carbon in WH can produce efficient hydrocarbons with the aid of alkali catalysts.

4.5 Raw Material for the Fertilizer Industry
The water hyacinth, according to Darius, Jane and Patrick, (2016) has the potential to be used as green or compost manure, which can directly be applied to the soil as green manure or mulched. The water hyacinth plant is optimal for compost by mixing it with animal manure, ash and soil after its been dried in the sun. The plant's lipids, proteins, fats starches and sugars are broken down by ‘microbial decomposition’ which is left to compost by the action of warm climates. This process produces compost that is free of pathogens. The compost, when applied to the soil, increases the fertility and quality of the soil, thereby improving crop yield. In Darius et al. (2016), it was established that manure of organic origin is more effective in improving soil quality than chemical manure. Furthermore, the shredded leaves and stalk of WH plants make a reliable quality of compost within a specified time when mixed with 8.1 ratios of cow dung and with a bit of curd. Liquid manure made from the water hyacinth contains 3.72%
nitrogen and 2.86% potassium, which can be used as macronutrient fertilizer. Composting WH using a biogas production plant has the advantage that methane emissions, which represent a potent greenhouse gas, can be collected and are not emitted to the atmosphere.

**4.6 Raw Material for the Pharmaceutical Industry**
According to Haggag, Abou and Abouziena, (2017), the water hyacinth contains some chemicals which can be used for medicinal purposes. Tulika and Mala (2015), declare after an observation that WH has some nutritional relevant compounds such as Glutathione, Flavonoids, Phenolics, Alkaloids, Terpenoids, Sterols, Glycosides, and other metabolic such as Saponin, Athroquinone, Phlobatannin, Quinone, Anthraquinone and Cardi Glycosides. These compounds, according to Tulika and Mala, (2015), have antimicrobial, antioxidant, wound healing, antitumor and larvicidal as well antifungal, antibacterial and antiviral effects (Haggag et al. 2017). Therefore, there has been increased research on the use of products from plants which have low toxicity and environmentally friendly to control different diseases.

**4.7 As Bio-Sorbent**
Biosorption is the process of using biological agents to remove metals, particulates and compounds from solutions. Depending on metabolic and non-metabolic processes, metals can accumulate in a solution. Pollution from heavy metals poses a serious environmental problem. Waste with various heavy metals is being discharged into the environment by different industries (Wang & Chen, 2009). According to Mahamadi, (2011), sufficient research work has been done to harness the benefits of the WH plant. The plant can be used as a phytoremediation agent and as a bio-sorbent for toxic metals using its dried roots, carbon and ash in removing heavy metals from solutions.
Priya and Selvan (2017) outlined that the biosorption potential of the WH plant in reducing different industrial wastewater contaminants has been significantly researched on. The bio-sorbent capability of WH can be used to reduce dyestuffs and
heavy metal concentration as well as having the ability to minimize specific parameters of physiochemical origin such as TSS, TDS, COD and BOD found in textile wastewater (Priya & Selvan, 2017). Despite its importance as sorbents, disposal of the pollutant bearing sorbents poses another challenge; therefore, there is a need for more research on the safe disposal of these bio-sorbents.
CHAPTER 5
METHODS OF CONTROL

Weeds that grow in the aquatic ecosystem create problems for humans and the environment. The WH plant, which is regarded as the world’s most problematic aquatic weed, has infested some significant bodies of water in more than 50 countries of the world, posing a series of many adverse effects. There is a need, therefore, to control and manage this noxious weed in order to sustain the natural lifeform of the freshwater ecosystem and its contribution to the livelihood of humans. Physical, chemical and biological control has been the method employed by both the government, stakeholders and NGOs in trying to control WH infestation. However, these methods have not been very successful due to their limitations and lack of adequate policy management.

5.0 Physical Control Method
The physical control method is the process of clearing WH from bodies of water with the use of machines such as weed harvesters, containment booms, construction of barriers like fences (Rachele & Andrew, 2013), nets to pull through WH mats and manual removal (UNEP2, 2013). Each specific method depends mainly on the level of infestation, resource availability and level of waterway use.

5.0.1 Mechanical Control using Machines
According to Rachele and Andrew, (2013), machines such as weed harvesters, truxor, ramps and excavators are used to harvest WH when the level of an infestation is on a large scale and will be more effective when integrated with herbicides. Proper disposal is required after harvesting to contain the viable seed or composting may be required. The use of machines has some limitations ranging from the following: it consumes time, it is labour intensive, high cost of equipment and some machines are not appropriate for sensitive vegetation and shallow water.

5.0.2 Booms and Fences
In Rachele et al. (2013), containment booms may be deployed to move WH mats from its original location to a place where it will be easy to use machinery in removing the
plant from the surface of water. Fences for containment are used in drainage areas where water flows to trap WH in order to prevent it from extending downstream. However, the booms and fences could be destroyed during flooding by WH mats and debris because seedlings and smaller plants can pass through the fences or under the booms, and this requires frequent maintenance.

5.0.3 Manual Hand Pulling

This involves the use of hands, nets, pitchforks and rakes to remove WH from the surface of the water. This process is employed when the infestation is in a relatively small area of the water body when there is a growth of new plants and when there is a fresh infestation and in drains or dams. The manual or hand pulling system requires intensive labour and cannot be employed in either large or medium size infestations and is less effective when the spread is faster than the removal process (Rachele et al. 2013).

5.1 Biological Control Method

The biological control method is the system of using natural enemies like insects and pathogens to decrease the development of invasive aquatic weeds. The use of biological agents to control WH began in 1962 (Julien, 2000) and in (UFS/IFAS, 2018), agents are used for biological control to reduce the proliferation of invasive plants by reducing seed, flower and leaf development, reducing population growth and reducing the size of the plant.

According to UNEP, (2013), the biological control method is employed to decrease the weed sufficiency to a non-problematic state, not to destroy it. There are various types of natural enemies to WH, and of importance are two weevil beetles native to South America, the *Neochetina Eichhorniae* and *Neochetina Bruchi* as well as WH moth species like the *Xubida Infusella* and *Niphograpta Albiguttalis*. These biological agents have been effectively used to control the proliferation of WH in some countries like Zimbabwe in Lake Chivero, in Louisiana, USA, Papua New Guinea, Mexico, Benin and in Lake Victoria, Kenya (UNEP, 2013). *Megamelus scutellaris*, which is a tiny insect and native to South America can also be used to control WH infestation. These
weevils decrease the size, flower, seed production and vegetative reproduction process of WH.

The biological control method is the most affordable, environmentally friendly and sustainable method that can be used to control WH according to Julien, (2000) and it is regarded as the most economically, sustainable and long term method for the control of WH according to Never, (2015). Despite its benefits, the use of biological agents is labour-intensive and might take a comparatively long time to establish. Furthermore, according to Rachele et al. (2013), differences in the climate of the native habitat and of the new habitat may aid or limit the successful establishment of these biological agents.

5.2 Chemical Control Method/Experiment

The chemical control method is the process of using selected herbicides like Glyphosate, Diquat and 2, 4-D amine to control the proliferation of WH (Jyoti & Garima, 2013). The use of herbicides like Paraquat, Amitrole, 2, 4-D acid, Glyphosate and Diquat around the world effectively decreases WH infestation. The use of a chemical is effective, fast and not as expensive as a mechanical control method, but requires specialized skills in its application (Never, 2015). According to Never, (2015), it has been noted that this method can only be used in small scale infestation and is less effective when dealing with huge infestation due to its threat on the environment and human health. (2015) also stressed that this method lacks sustainable long-term control as it affects the quality of water and marine organisms.

Jyoti and Garima (2013) noted that these chemicals pollute the water bodies and the dead plant after herbicidal application decreases the oxygen content of the water leading to secondary pollution, which is injurious to fish. In Never, (2015), glyphosate was reported to affect marine organisms, and it is solely harmful to plants as its application affects the roots of green plants and restrain the specific amino acids from forming, which kills the plants. The chemical control method creates room for the growth of other organisms as non-targeted plants are also killed and lead to algal bloom due to the decomposition of the plants. The herbicide 2, 4-D may cause cancer
as dioxins form after its application and break down into different extent of chlorination (Never, 2015).

Managing aquatic weeds depends mainly on the sensitivity of their native environment, and according to Charudattan (2001), managing aquatic weed comes with the task of employing less expensive methods, which are safe and effective, with little or no side-effects using the most sustainable and efficient method. This is why El-Shahawy (2015) conducted an experimented study “under wire-house conditions” to ascertain the ability of some natural reference chemicals such as formic acid, propionic acid, acetic acid and citric acid at 10, 15, and 20% different concentrations to control WH using 1.8kg of herbicidal glyphosate. The result of the experiment showed that these chemicals at different concentrations were able to effectively decrease the development of WH faster than the glyphosate. The combination of propionic and formic acid proved more effective in controlling WH.

Similarly, Agidie, Sahle, Admas, and Alebachew (2018) conducted an experiment under “shade level” to find out the effects of specific chemicals such as sodium chloride, glyphosate, potassium chloride, acetic acid and glyphosate at different concentrations of 15, 20 and 25% to control WH. The result of the experiment showed acetic acid was most effective in reducing and killing the tissue of WH within days.

In order to determine the efficacy of natural chemicals in controlling other aquatic weeds such as water lettuce (see Figure 6), a controlled experiment was conducted between Friday 23 August and Monday 26 August, 2019 using acetic acid, formic acid and citric acid at different concentrations of 10%, 0.1% and 10% respectively.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Concentrations</th>
<th>Quantity of water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic Acid</td>
<td>10%</td>
<td>180 ml</td>
</tr>
<tr>
<td>Formic Acid</td>
<td>0.1% (4 drops)</td>
<td>200 ml</td>
</tr>
<tr>
<td>Citric Acid</td>
<td>10%</td>
<td>180 ml</td>
</tr>
</tbody>
</table>

Acetic acid is significant at 10%, Formic acid significant at 0.1% and Citric acid significant at 10%.

Table 3. Effect of acetic acid, formic acid and citric acid at different concentrations on the growth of aquatic weed under controlled conditions.
Figure 7: Water lettuce before the experiment.

Figure 8: Start of application of acetic, formic and citric acid.
Figure 9: Effect of acetic acid after two hours of application.

Figure 10: Experiment after five days of application.
5.3 Results and discussion

In Figure 6, water lettuce was collected, and the leaves, stems and tissues were fresh and intact. Figure 7 shows the beginning of the experiment immediately after the different application of the chemicals. Acetic acid at 10% concentration was most effective in shrinking the weed as the colour of the leaves changed as compared to formic acid (0.1%) and citric acid (10%) after two hours of application in Figure 8.

After four days of the experiment between Friday 23 August 13:30 and Monday 26 August 9:00, 2019 in Figure 9 and Figure 10, acetic, formic and citric acid affected the leaves, stem, colon and roots of the aquatic weed. The aquatic weed was 100% repressed by acetic acid in the shortest duration.

This experiment demonstrates that herbicidal application in a bid to control WH not only controls its growth and proliferation but also affects non-targeted aquatic weeds. These chemicals, therefore, if appropriately researched, could aid in the management of WH in a cost-effective and sustainable manner.
5.4 Integrated Control Method
According to Hill and Coetzee (2008), integrated control is the act of initiating a comprehensive management system, which includes multiple units of effective use of herbicides, the appropriate use of mechanical power, the efficient use of biological agents in the control of WH in the infested area and the responsibility of decreasing the level of phosphate and nitrate into water bodies. It is also the intelligent integration of insects, pathogens and herbicides in the management of the proliferation of WH (Charudattan, 1986).

5.5 Conclusion
Research has noted that these chemicals dissolve quickly into water and carbon dioxide in the environment; they are also very effective in controlled conditions more than in field conditions. Certain factors, such as abiotic and biotic factors may disturb the mechanism of these chemicals in the field. Chemical control method requires a repeated application as seeds of aquatic weed, notably WH can cause re-infestation or surviving plants could increase in number. Chemicals with natural components are most effective in the control of terrestrial weed while little is mentioned of its use as an aquatic weed control method. It was shown through experiment though, that even the more environmentally acceptable chemicals will have collateral effects on other plants, such as water lettuce, which was taken as an example here. The physical control method proves to be the most viable method of control as it gives room for natural restoration of the water bodies after infestation. However, this method is expensive and time-consuming.
CHAPTER 6
EVALUATION OF REGIONAL APPROACH

6.0 International Approach

In order to control and manage the continued spread of WH around the world, measures have been put internationally by governments and international organizations. These consist of technical support to affected areas, and research efforts on the effective management of the weed. According to Luis & George, (2000), “the International Development Research Centre (IDRC)” with its People, Land and Water Program (PLaWP) formed an approach in Africa and the Middle East (AME) in 1996 to evaluate the level of damage caused by WH infestation. This programme tried to identify and analyse WH management setbacks in the region, to raise the region's awareness of the proliferation and impact of WH infestation, and to evaluate the most effective management tool in controlling WH infestation.

Beyond the initiative in AME, international organizations and agencies that have provided technical support and research for the effective management of WH infestation include the Commonwealth Scientific and Industrial Organization (Australia) (CSIRO), the Centre for Agriculture and Biosciences International (CABI), the International Institute for Tropical Agriculture (IITA), the United Kingdom Commonwealth Science Council (CSC), the Food and Agriculture Organization of the United Nations (FAO), the Japan International Cooperation Agency, the United States Agency for International Development (USAID), the United Kingdom Department for International Development (DFiD), the Gesellschaft für Technische Zusammenarbeit (GTZ) (technical-cooperation agency), the Danish International Development Agency and the European Union.

6.1. Evaluation and Analysis of Regional Data

As part of the present work, a questionnaire was developed and distributed to local residents of Abbiati Village in Cross River State. Two questionnaires were filled out by the NIMASA agency representative, who filled out the questionnaires after interviewing two residents, as described in section 3.2. Data on the spread of water
hyacinth, its effect on fishing, transportation, water quality, mode of control as well as its impact on the environment was collected and presented.

Based on the response from the two (2) questionnaires returned, the water hyacinth was observed in the surrounding area of Mbat-Abbiati creek, an area in the flank of Calabar, which is part of the Great Kwa River in Akankpa, Cross River State. This creek is one of the central water bodies seen as a source of drinking water, as a means for irrigation and seafood for the inhabitants. This creek is found near the lower part of the river and is prone to an outflow of waste from industrial activities within the region.

One of the two residents responded that the water hyacinth was first sighted within Mbat-Abbiati creek between 1986 and 1990. This would agree with the time frame of
the water hyacinth proliferation reported by Uka et al. (2007), that WH first entered Nigeria in 1984 through the Badagry creek, extending towards the coastline of over 20 out of the 36 states in Nigeria. At this time WH was reported to first have disrupted the economic activities of the riparian fisher folks in the area. In the second response, the respondent answered ‘None of the above 4’ in what is a conflicting response of WH characteristics.

Q3. Does water hyacinth spread very fast IN YOUR COMMUNITY?

The proliferation speed of the water hyacinth within the creek was specified as very fast by both respondents. WH can spread very fast in water bodies with a high level of nutrients, which is apparently the case with the creek in relation to its downstream location in areas where mining and quarrying activities are carried out.
One of the two respondents stated that the HW had spread within Mbat-Abbiati and the other one stated that it had spread to Oberekkai creek as both creeks are connected and lie along the same channel. Mbat-Abbiati and Oberekkai creeks are part of the major rivers that make up the Great Kwa River that drains eastward through the city into the Calabar Estuary. The river is used for artisanal fishing, aquaculture and water transportation.

Both respondents answered that the spread of WH occurred within a month. According to Su et al. (2018), the proliferation of WH under favourable conditions can multiply in a week and in a year, and it can also reproduce ramets to about 140 million, which can cover a large area of surface water. This is due to the plant reproducing
vegetatively and propagates sexually through seeds. The seeds can stay for six years in water, making it hard to control.

Both of the respondents answered that before the infestation of the water hyacinth in Mbat-Abbiati creek, fishing activities were a form of occupation. This may have serious socioeconomic impacts on the community since fishing is typically a source of income for the people of artisanal communities.

One of the respondents answered that the fishing activities decreased from moderate to low after WH infestation, while the other respondent answered that the fishing activities remained constant at a moderate level. However, this is due to the level of infestation as WH has blocked access to the major fishing grounds. Oladimeji (2016) noted that WH mats can restrict access to fishing grounds, disrupt fishing boats and
nets leading to reduced fish catch and loss of valuable fish species. The mats can also alter the breeding ground for fish, which ultimately affects fishers’ livelihood and reduces the quality of life of the riparian communities by increasing the fishing cost.

Both respondents answered that the proliferation of WH had significantly affected water transportation in the study area. This can have a significant impact on communities since small boats are often the only means of moving from one community to another within the creeks. It is known that dense mats of WH can block water channels and prevent the passage of small boats and canoes, which ultimately increases transportation fares (Alimi & Akinyemiju, 1991).
According to the respondents, the quality of water in the study area has been altered as increased particulate substances could be found in the water bodies. However, the water can be used for drinking since the particulate substances is at low level according to the respondents. Though, this was not measured but the information was supplied by one of the respondents as verbal information during the interviews.

One of the respondents answered that the method used earlier to manage WH infestation was through physical control method while the other respondent supplied that the method used was through hand pulling. The results indicate that within the study area, an earlier effort was made by the community to control the spread of WH. The community was engaging in a physical control method, which involves manual hand pulling.
One of the respondents answered that WH affected biodiversity to a very significant extent, whilst the other respondent answered that WH affected biodiversity to a significant extent. It has been argued by Muhammad and Aftab (2019) that WH mats can reduce biodiversity. It may reduce the production of phytoplankton as the mats prevent sunlight from reaching below the water bodies, thereby disrupting the process of photosynthesis.

From the responses given in the questionnaire, it was unclear whether the water hyacinth spread faster during the rainy season and slower during the dry season. Akinyemeju (1987) has pointed out that WH spreads faster during the rainy season due to the reduced salinity within the water bodies, and reduces during the dry season as a result of increased salinity. The leaves of the water hyacinth may dry off but can
regrow from the stems under the right conditions. The seeds no matter the variations in weather can stay alive for up to 20 years according to Paul and Wood, (2012).

### 6.1.1 Socio-economic Impact of Water Hyacinth

Water hyacinth infestation in freshwater ecosystems disrupts socio-economic activities of water uses such as the restriction of access to boats, hampering navigation and reducing recreational activities. Water hyacinth mats restrict access to fishing areas leading to a reduction in fish catch and also alters the composition of fish stocks. Water hyacinth infestation disrupts irrigation schemes used for agricultural purposes, as well as interrupting municipal and industrial water supplies according to (Villamagna & Murphy, 2010). The rate of fish caught in Lake Victoria has decreased as there was no access to areas used for fishing, and the mats also hindered accessibility to markets, which eventually raised the cost of tilapia fish and materials used for fishing.

Water hyacinth infestation is a significant problem for fishery development in the north-central region of Nigeria. It restricts access to fishing, transportation, navigation and loss of equipment used for fishing, causing a reduction in fish catch mainly economically viable fish like mudfish and tilapia found along river reefs and shores (Oladimeji et al. 2016). Furthermore, the water hyacinth impedes hydro-electric power generation and increases fishing expedition cost as a result of requirements of labour to clear the plant.

According to Oyinloye, Owoeye and Ogunlade, (2018), water hyacinth infestation affects the social and economic livelihood of the coastal communities in Ondo State Nigeria. The mats of water hyacinth plant on the lagoon restrict access to fishing grounds as they can lose their boats, and rate of fish sales is reduced due to the inability of fish to survive in the lagoon. The mats of the water hyacinth obstruct natural water flow and waterways during flooding, thereby leading to the loss of livestock, equipment and infrastructure. These large mats, which weigh up to 450 tonnes, are costly and challenging to be removed and end up destroying pastures and crops. It also
hinders swimming, boating, water transportation (Oyinloye et al. 2018) and reduces the quality of water for drinking (Ogunlade, 2002).

### 6.1.2 Environmental Impact

Water hyacinth infestation changes the level of oxygen in a freshwater ecosystem, which suffocates fishes and other marine organisms and alters the composition of flora and fauna (Muhammad & Aftab, 2019). The mats of WH alter freshwater food web, ecosystem and shelter pest, snakes and insects (Toft, Simenstad, Cordell & Grimaldo, 2003). The mats of WH plants restrict light from touching the water column, destroy biodiversity and the aquatic native plants as well as the ecological community and hydrology as they compete for nutrients (Muhammad & Aftab, 2019). The water hyacinth leads to excessive loss of water through evapotranspiration up to 1.8 times more than surface water free of WH infestation (Habtamu, Kelemu & Fenta, 2019). It leads to increased sedimentation within the Delta region of Nigeria (Ndinwa et al. 2012) and constitutes breeding grounds for snails, mosquitoes and other vectors that cause diseases for humans such as malaria, dysentery, schistosomiasis, cholera, encephalitis and filariasis (USFWS, 2018).

### 6.1.3 Conclusion

The assessment of the distribution and spread of the water hyacinth in Mbat-Abbiati creek and Nigeria indicates that the weed with its dense mats has infested all the major coastal communities in the various states of Nigeria leading to both socio-economic and environmental impacts. Therefore, there is an urgent need for the Government and the stakeholders to combine resources in the management of this noxious aquatic weed through the physical method and the use of environmentally friendly chemicals like acetic and formic acid. Utilization options should be considered as a means of managing the WH plant as its utilization can create employment and income for the artisanal communities. Therefore, the Government can assist these communities infested with WH to purchase mechanical weed harvesters and with the aid of herbicides to carry out large scale control.
Limitations affected the level of research due to time, finance and environmental factors (rain), which made it difficult to access the extent of infestation within the study area, as well as the poor response from the supposed respondents.

6.1.4 Regional Approach

In order to control and manage WH infestation in West Africa, Ajuonu et al. (2010), highlighted that the Economic Community of West African States (ECOWAS) through financial aid from the African Development Bank (ADB) provided an initiative for a project to adopt the integrated control method of using biological pest management, physical method of control and weed utilization through composting. According to Harouna (2004), ECOWAS with financial aid from ADB embarked on a study on “Regional Floating Weeds Control Programs in the ECOWAS Member States” from 1992 to 1995 and formed the Co-ordinated Integrated Management Project (CIMP) in the region to manage aquatic weeds within the coastal states of Nigeria, Benin, Niger, Mali, Côte d’Ivoire, Ghana, Mauritania and Senegal. A Regional Floating Weeds Control Program in the ECOWAS Member States was initiated to be financed by the ADB in 2002 in other to control and manage aquatic weeds (Harouna, 2004).

6.2 National Approach

During the early stages of WH infestation in Nigeria, the manual method was used to control WH, and as the proliferation increased, the mechanical removal method was employed in 1985 to control its spread (Charudattan, Ricardo, Ted & Christine, 1995). In the same year, the government of Nigeria set up the Water Hyacinth National Committee through the National Agency for Science and Engineering Infrastructure (NASENI) to harmonize the chemical, mechanical, and biological control methods as well as initiating ideas for the utilization of WH and monitoring of its spread. The committee worked with local governments, ministries, departments and the River Basin Authority responsible for the management of WH in Nigeria. The committee was also required to form bilateral agreements with bordering countries such as the
Republic of Niger and the Republic of Benin to control the spread of WH, which is trans-boundary because of the connected water bodies (Charudattan et al. 1995). The mechanical control method was expensive and carried out by local companies only when the need arises to clear WH along the coastal areas, particularly when the water channels were blocked. The physical control method was employed to complement the mechanical control method. The Institute of Ecology and the Obafemi Awolowo University Institute of Ecology Ile-Ife researched the use of the chemical control method. Diquat, terbutryn and glyphosate were used in some water bodies, which recorded effective results in destroying WH. The use of the chemical control method was not supported by the Nigerian Government due to its negative impact on the environment and human health. The biological control method was the most favoured by the Nigerian Government for the long term management of water hyacinth infestation in Nigeria. The biological control method was done through NIHORT, which introduced *Neochetina eichhorniae* weevil species. (Charudattan et al. 1995).

### 6.3 Water Hyacinth Management Setbacks

Although the discussion of control methods has shown that in principle Africa and the world have the expertise to tackle WH infestation, there seems to be little success in controlling the weed. This is mostly due to the following reasons according to Navarro & Phiri (2000): Bureaucracy and insufficient organization is the major factor limiting the ability of units and departments responsible for the execution of policies to function effectively as they carry out their duties without adequate communication and coordination due to lack of access to resources. This leads to misplaced objectives in not responding to the danger of WH infestation. Inadequate access to and information flow from policymakers is another constraint to managing WH as identified by stakeholders. In most of the cases, control efforts have been made only when the negative impact of the infestation reaches high levels due to lack of technical and financial commitments.

In addition, management strategies and control policies are lacking in most countries infested with WH. Furthermore, an integrated strategy for the control of WH
Infestation is grossly inadequate at both regional and national levels. There are difficulties in establishing the appropriate agency with the technical know-how in managing infestations, lack of participation of stakeholders in decision making and management strategy as well as lack of funds to carry out appropriate control methods.

In Nigeria, WH suitable management option is hindered by lack of communication and coordination, inadequate financial aid and bureaucracy Luis & George, (2000).
CHAPTER 7
SUMMARY AND CONCLUSIONS

The water hyacinth is a free-floating perennial aquatic plant with spongy tissue, which is highly invasive and doubles every 4 to 7 days in a high polluted nutrient-rich freshwater ecosystem. The water hyacinth is native to the Amazon Basin in South America and was discovered in 1816. It was introduced in the United States in 1884. The proliferation of WH was recorded in more than 50 countries within 5 continents and regarded as the world’s most troublesome weed in the tropical and subtropical parts of the world. The water hyacinth reproduces vegetatively through seeds. The water hyacinth has drawn international attention as an aquatic invasive species. It is found in streams, lakes, wetlands, ponds, waterways and estuaries, causing huge social, economic and environmental problems around the world.

In Africa, water hyacinth is the most prevalent and disruptive plant species in the aquatic ecosystem. It was found in Europe around the Azores; in Asia, it was discovered around the wetlands of the Deltas in the Mekong and has infested over 40,000 hectares of water bodies. The infestation of the water hyacinth in Nigeria impedes fishing and transportation activities; it disrupts irrigation and drainage systems; it hinders water supply by clogging water channels and reduces the quality of water; it also disrupts hydroelectric power generation. In other regions of the world, the water hyacinth depletes oxygen in water, which alters the quality of water, leading to the loss of biodiversity. Further, it damages infrastructure, creates breeding grounds for pests and vectors of diseases like malaria and blocks waterways which hinder fisheries, recreation and agriculture. In order to preserve the environment and well-being of humans, some control methods such as chemical, biological, physical and integrated methods of control have been used to prevent the pressure of the water hyacinth on water resources. These control methods have not been very successful because of the nature of the environment where the water hyacinth grows, the type of control method and management policy. Water hyacinth wet and dry biomass could be harvested since it has the potential to be used for biogas production, compost manure and as bio-sorbent.
for heavy metals in water bodies, for the production of ethanol and for making baskets and fireboard. More research is needed to ascertain the efficacy of the use of certain eco-friendly chemicals like acetic acid, formic acid and citric acid for the control the water hyacinth.

Therefore, the international community, in collaboration with governments of various nations, specialized agencies and international organizations, provides both technical and financial support to enhance research on the most viable control method to manage the weed. Hence, there is a need for an integrated approach of appropriate policy where there is participation between key stakeholders, governmental departments and the general public in the management of the water hyacinth within the catchment area.

7.1 Recommendations
Since the water hyacinth is a transboundary problematic aquatic weed, a regional research strategy should be established within the ECOWAS to enhance the management procedures to address the negative impact of water hyacinth infestation in the region. Therefore, the following is recommended:

- National strategy for species diversity and ecological studies for marine ecosystems should be established for effective eradication, control, management of waterways and prevention of re-infestation of the water hyacinth.
- An interdisciplinary approach should be created for orientation training, seminars, workshops and courses on the negative impact of the water hyacinth infestation and the most viable method for control.
- Management strategies should be developed to identify the distinctive roles of governmental departments, municipal councils, local community and stakeholders in the control and management of the water hyacinth.
➢ An action plan should be developed to carry out an awareness campaign on the socioeconomic impact of the water hyacinth and to involve stakeholders, local and riparian communities in the biological and manual control measures of the water hyacinth.

➢ An action plan should be developed to lower the level of nutrients in water bodies by control both point and non-point sources of pollution.

➢ A sustainable drainage management policy should be created for sustainable agricultural practices in riparian communities in other to prevent agricultural runoff.

➢ Adequate funding for the control and management of the water hyacinth should be provided for in the annual budget.

The utilization of water hyacinth biomass as a raw material for the industry should be used as a means for control, not as a means for propagation.
References


Appendix 1

QUESTIONNAIRE
Please tick or complete where necessary this questionnaire as honestly as you can. All information supplied will be used solely for the purpose of this study and will be treated with the utmost confidentiality. Your co-operation will be highly appreciated. Thank you in advance.

1. Have you ever experienced water hyacinth within your community? Yes ☐ No ☐

2. If yes, from your perspective, when was water hyacinth first sited in your community and within the Niger delta?
   Between 1980 ☐ and 1985 ☐ Between 1986 ☐ and 1990 ☐
   Between 1991 ☐ and 2000 ☐

3. Does water hyacinth spread very fast in your community? Yes ☐ No ☐

4. If yes where……………….. To where……………………

5. How fast did it spread? Within days ☐ Weeks ☐ Months ☐

6. How was fishing activities in your community before the spread of water hyacinth? High ☐ Moderate ☐ Low ☐

7. How is fishing activities after the spread of water hyacinth in your community? High ☐ Moderate ☐ Low ☐

8. To what extent does the spread of water hyacinth affect transportation within your community? Not Significant ☐ Significant ☐ Highly Significant ☐

9. Has the spread of water hyacinth affected the quality of water for drinking? Yes ☐ No ☐
10. If yes, how has the spread of water hyacinth affected the quality of water for drinking? No trace of particulate substance □ Low particulate substance □ High particulate substance and odour □

11. Does the spread of water hyacinth enhance recreation within your community? Yes □ No □ Yes □ No □

12. To what extent has the spread of water hyacinth affect agricultural activities within your community? Insignificant extent □ Significant extent □ Highly significant extent □

13. From your perspectives does water hyacinth benefit your community in the following areas? Yes □ No □

14. What ways have been employed by government to control water hyacinth? (a) Biological control □ (b) Physical control □ (c) Chemical control □

15. Has your community put up any effort to control it? Yes □ No □

16. If yes, how did the community control the water hyacinth? (a) Biological control □ (b) Physical control □ (c) Chemical control □

17. Did the government engage your community in the process of harvesting water hyacinth? Yes □ No □

18. If yes, was there any incentive for community effort? Yes □ No □

19. What method was used earlier for controlling water hyacinth? ………………………

20. Has any NGO or specialized agencies attempted to clear water hyacinth in your community before? Yes □ No □

21. To what extent has water hyacinth affected the growth of biodiversity? Insignificant extent □ Significant extent □ Very significant extent □

22. What season does the water hyacinth spread the most? Rainy season □ Dry season □
23. What area of your community does the water hyacinth affect the most?.............