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IMPACTS OF WATER HYACITH ON THE FISHING INDUSTRY AT THE WINAM GULF, KISUMU COUNTY

BY
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A RESEARCH PROJECT REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE BACHELOR’S DEGREE AWARD IN ENVIRONMENTAL STUDIES (ENVIRONMENTAL PLANNING AND MANAGEMENT)
DECLARATION
This report is my original work and has not been presented for a degree award in any other university.

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APPROVAL
This report has been submitted for examination with my approval as a university supervisor.

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DEDICATION

This project is dedicated to my parents for their love, care and support
### ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>UNEP</td>
<td>United Nations Organization Programmes</td>
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<tr>
<td>LVEMP</td>
<td>Lake Victoria Environmental Program</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
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<tr>
<td>KMFRI</td>
<td>Kenya Marine and Fisheries Research Institute</td>
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<tr>
<td>NDVI</td>
<td>Normalized Difference Vegetation Index</td>
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<tr>
<td>NGO</td>
<td>Non-Governmental Organizations</td>
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<tr>
<td>FVI</td>
<td>Floating Vegetation Index</td>
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<tr>
<td>KARI</td>
<td>Kenya Agricultural Research Institute</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture organization</td>
</tr>
<tr>
<td>CIFA</td>
<td>Committee for Inland Fisheries of Africa</td>
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<tr>
<td>LVFO</td>
<td>Lake Victoria Fisheries Organization</td>
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ABSTRACT

Fresh water bodies constitute a vital component of a wide variety of living environments as integral water resource base in many human societies in the world. Water hyacinth has invaded Freshwater systems in over 50 countries on five continents and changes to its density have the potential to affect other ecological and human communities in areas where it is established either positively or negatively. The hyacinth, since its introduction in Kenya, has been a menace to the riparian communities, causing several problems. However, the range of problems with water hyacinth infestation is in general terms widely known, the real extent of the influence on the socioeconomic status and welfare of the people who depend on the affected water for fish. The study focused on the impacts of water hyacinth on the fishing industry at the Winam Gulf, Kisumu County, the study methodology was mainly GIS and Remote Sensing to show the spread and pattern of water hyacinth throughout the years from the year 2000 to 2010. The study also relied on secondary data to show the impacts of water hyacinth on the fishing industry.

The study describes an approach based on the time-series of MODIS to derive the temporal behavior, the abundance and distribution of the floating macrophytes in the Winam Gulf (Kenyan portion of the Lake Victoria). To this end, the study consider the NDVI values computed from the MODIS imagery time-series from 2000 to 2009 to identify the floating macrophytes cover and an appropriate bio-optical model to retrieve, by means of an inverse procedure, the concentrations of chlorophyll a, colored dissolved organic matter and total suspended solid. The maps of the floating vegetation based on the NDVI values allow us to assess the spatial and temporal dynamics of the weeds with high time resolution. The studies finding was that the Area covered by water hyacinth at the Winam Gulf in the year 02/12/2000 was 531.99 Hectors and in 14/12/2010 the area was 37,000 Hectors. The study finding was also that fish production has drastically fallen and therefore income for those whose income generation activities revolve around fish production has fallen, during the pre- water hyacinth period (1986-1991), the weekly benefits from the fish production was KShs 68,000 and during the post-water hyacinth period (1992-2010), the weekly catch was reduced to KShs 53,820. Some fish processing plants have closed down and water transport operators are almost out of business due to Water hyacinth. The findings therefore suggest that the lifestyle of the people living near Lake Victoria and depend on it, in one way or another has changed considerably. On the basis of the findings, it is generally recommended that the government, NGO's and other interest groups should involve the local residents in both policy making and practical removal of the weed from the lake. It is also recommended that this be treated with urgency as the effects of the weed are growing with time.
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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Fresh water bodies constitute a vital component of a wide variety of living environments as integral water resource base in many human societies in the world. They have been regarded as key strategic resources essential for sustaining human livelihood, promoting economic development and maintaining the environment (Uganda National Water Development Report (UNWDR), 2005). Utilization of freshwater resources include use as source of drinking water, fishing activities, sites for domestic and industrial effluents discharge, recreation and transportation activities.

Water hyacinth, a floating vascular plant, is known to cause major ecological and socio-economic changes (Center, 1994). Originally from South America, water hyacinth is one of the world’s most prevalent invasive aquatic plants. It has become naturalized in many warm areas of the world. Water hyacinth has invaded freshwater systems in over 50 countries on five continents; it is especially pervasive throughout Southeast Asia, the southeastern United States, central and western Africa, and Central America (Bartodziej & Weymouth, 1995; Brendonck et al., 2003; Lu et al., 2007; Martinez Jimenez and Gomez Balandra, 2007).

The first reference to water hyacinth in the United States was at the beginning of the 20th century on the occasion of the Louisiana Purchase (Sculthorpe 1967). The spread continued to Florida where there are many references to control the spread and infestations that occurred (Schardt 1984). It was also introduced into North and South Carolina. In the countries of South America, there are reports of its presence in 1902 in Brazil, 1942 in Argentina, 1959 in Paraguay, Uruguay, Bolivia, Ecuador, and Colombia, 1976 in Venezuela, and 1979 in Chile. In Central America, it is cited in Mexico, Nicaragua, Costa Rica, and El Salvador in 1965, Panama in 1966, and Puerto Rico and the Dominican Republic from 1971. Water hyacinth grows rapidly (Penfound and Earle, 1948) forming expansive colonies of tall, interwoven floating plants. It blankets large waterbodies, creating impenetrable barriers and obstructing navigation (Gowanloch and Bajkov,1948; Zeiger, 1962). It has been reported that floating mats block
drainage, causing flooding or preventing subsidence of floodwaters. Large rafts accumulate where water channels narrow, sometimes causing bridges to collapse. Water hyacinth hinders irrigation by impeding water flow, by clogging irrigation pumps, and by interfering with weirs (Penfound and Earle, 1948).

In Europe, the water hyacinth was possibly introduced as an ornamental plant in the first third of the 20th century in Portugal, because the first reference to its presence there dates from 1939. Since then, it has spread over the central-west of the country through irrigation canals and currently exists in the middle and lower Sado and Tagus Basins (Guerreiro 1976; Figueiredo et al. 1984; Amaral and Rocha 1994). Hyacinth infestations block access to recreational areas and decrease waterfront property values, oftentimes harming the economies of communities that depend upon fishing and water sports for revenue. Shifting water hyacinth mats sometimes prevent boats from reaching shore, trapping the occupants and exposing them to environmental hazards (Harley, 1990). Water hyacinth infestations intensify mosquito problems by hindering insecticide application, interfering with predators, increasing habitat for species that attach to plants, and impeding runoff and water circulation (Seabrook, 1962).

In Africa, the water hyacinth was first reported in Egypt between 1879. It is considered one of the most notorious weed species in tropical West Africa (Food and Agriculture Organization (FAO), 2000). Water hyacinth infestation of freshwater ecosystems has been recently reported by several workers (Luken and Thieret, 1997; Bolorunduro, 2000; Osumo, 2001; Masami et al., 2008); and its major effect appears to be disruption of normal ecological functioning of aquatic ecosystems where it is found thriving. Beneficial effects of the water hyacinth have also been reported as an aid in water purification through conversion of toxic ammonia to usable nitrates as well as capacity to absorb heavy metals and organic compounds from water body (Simeon et al., 1987; Cowx and Welcomme, 1998; Ingole and Bhole, 2002). The influence of aquatic macrophytes on the limnological properties of water bodies has been recognized (Petre, 2000; Lee and McNaughton, 2004). They may, therefore, be regarded as efficient indicators of water quality.
The weed was first reported in the Ugandan portion of Lake Victoria in 1990 (Thompson, 1991). It is believed that it entered the lake in 1989 via the Kagera River, which has its mouth in the Ugandan portion of the lake (Muli 1996). Estimates made in April 1999 and in August 1999 indicated that the input of water hyacinth into Lake Victoria through the River Kagera was 3.5 ha per week (Mailu, 2001).

According to Mailu, the water hyacinth infestations in the portion of Lake Victoria in Tanzania in 1999 were located in Mara Bay, Bauman Gulf, Speke Gulf, Mwanza Gulf, Emin Pasha Gulf and Rubafu Bay. Currently, water hyacinth occurs also in the Kagera, Sigi and Pangani rivers, as well as in streams and water ponds around Dar-es-Salaam and close to Lake Victoria. The total cover estimate of water hyacinth in the Tanzanian waters of Lake Victoria was 2000 ha (Mailu, 2001).

Water hyacinth was first sited in the Kenyan side of the lake in 1992 (Republic of Uganda, 2005). Water hyacinth occurred in form of stationary mats in sheltered bays and along much of the lakeshore, in addition to the mobile mats that were propelled around the lake by winds, waves and water currents (Balirwa, Wanda, and Muyodi, 2009). Despite water hyacinth’s invasive nature and dominance in Lake Victoria in the 1990s, water hyacinth largely disappeared from Lake Victoria by the end of 1999. For instance, no water hyacinth was found on the Gulf from April 2002 until October 2004, only appearing again at the next measurement date of December 2005 (Gichuki et al, 2011).

At the Winam Gulf in Lake Victoria the water hyacinth is mainly found in inshore and shallow areas to which it is swept by currents and sometimes in patchy offshore areas. It spreads fast in shallow (< 6m) bays and inlets with mud bed surfaces. Lake Victoria’s tropical location, shallow depth and nutrient enrichment provide favorable conditions for its proliferation. The 'mats' of aquatic plants reduce dissolved oxygen by restricting the exchange of oxygen across the air/water interface. They also affect wind-driven water movement and impede mixing of oxygen-rich surface water (Smith-Rogers, 1999). The oxygen can be reduced to such low levels that it leads to massive fish kills due to oxygen depletion in the water column, this result in loss of aquatic biodiversity.
(Muli, 1996). The plant can also block waterways, such as fish landing beaches and piers and prevent boats from docking thus hindering transportation by the fishermen.

1.2 STATEMENT OF THE PROBLEM

At the Winam Gulf water hyacinth has significant negative impacts on the fishing and socio-economic condition on the community around the area. Fishing Declines in fish landings are estimated at 50-75%. This is partly attributed to declines in habitat quality of the Lake Waters and over-fishing. Sheltered bays have suffered nutrient reduction interfering with breeding and nursery grounds for fish, particularly tilapia. The presence of expansive mats of water hyacinth choking bays has interfered a great deal with harbor and fish landing operations. Reduced accessibility to the harbors has occasioned unprecedented delay in commercial water-borne transport for people and goods resulting in losses for fishermen especially when their catches rot due to delays. There’s also loss of fishing time due to obstructed beaches. Fuel consumption for fishing boats and lamps is doubled or even tripled.

The weed has choked important waterways and landings. Commercial transportation and services for people and goods, especially movement by small boats are obstructed. Docking the large steamers are regularly delayed.

1.3 RESEARCH QUESTIONS

1. Has the water hyacinth within the Winam Gulf continued to grow and spread throughout the years between 2000 and 2010?
2. In what way has the spread of water hyacinth within the Winam Gulf affected the fishing industry?
3. What role do the urban areas around the Winam Gulf play in the problem of Water Hyacinth?
4. What other effects does the water hyacinth have in the Winam Gulf?
1.4 RESEARCH OBJECTIVES

1. To determine the spreading patterns of water hyacinth at the Winam Gulf.
2. To determine the impacts of water hyacinth on the fishing industry at the Winam Gulf.
3. To find out the role the urban areas contribute to the spread of water hyacinth.
4. To determine other problems caused by the water hyacinth.

1.5 RESEARCH HYPOTHESIS

The presence of water hyacinth has negative impacts on the fishing industry in the Winam Gulf.

1.6 JUSTIFICATION OF THE STUDY

A lot of research work has been done on water hyacinth, but most of it has concentrated on the control methods not on its impacts on the fishing industry. The appearance and the large scale infestations of water hyacinth have caused more havoc than good to the users of the lake. The effects include hampering the lake transport, fishing and travelling on the Lake is almost impossible; goods cannot be imported and exported as they ought to be and many landing sites have been closed. Lots of resources both finance and human resources have been devoted to help control its spread. These resources could have been invested elsewhere.

This study therefore sought to assess the effects on water hyacinth infestation on the fishing industry. The area which is chosen for this study borders the lake and its easily accessible thus forms a strategic location for studying the effects of water hyacinth. The population is severely affected in terms of fisheries) oriented activities like sand harvesting, charcoal making among others within the study area.

The study is aimed at highlighting the impacts of water hyacinth on the fishing industry, as well as the socio-economic activities around the Lake. The study will concentrate on the Winam Gulf since its highly infested by the water hyacinth. By using remote sensing and GIS, the study will be able to show how the water hyacinth has been spreading from the year 2000 to 2013, hence determining whether the water hyacinth has been decreasing or increasing throughout the years.
1.7 SIGNIFICANCE OF THE STUDY

By highlighting the impacts of water hyacinth in Lake Victoria, it could arouse interest from concerned parties in that the findings of the study would provide insight to the institutions undertaking similar research. The findings would also be important to the major stakeholders such as the Government and Non-governmental organizations, in that it assist them in decision making and awareness creation on the impacts of water hyacinth on the fishery and the economy of the community around the area of study, thus enhancing sensitization and formation of better policies in the management of the Lake hence promoting sustainability by reducing pollution and protecting the ecosystem.

1.8 SCOPE AND LIMITATION OF THE STUDY

The study area was limited to the Winam Gulf, Kisumu County. The study focuses on the impacts of water hyacinth on the fishing industry, the study also examine the nature and extent of water hyacinth at the Winam Gulf, by examining how the water hyacinth has continued to spread throughout the years, the study focuses on the period from 2000 to 2013.

Water hyacinth as a water weed on Lake Victoria moves by wind and wave action thus it was difficult to predict and access the newly affected areas. The time allocated for collecting data was also limited. A financial constraint since it was required to travel to the area of study to collect data and examine the area of study.

DEFINATION OF TERMS

**Water hyacinth:** Is a free-floating perennial aquatic plant (or hydrophytes) native to tropical and sub tropical South Africa with thick glossy, ovate leaves, water hyacinth may rise above the surface of water as much as 1 meter in height. The leaves are 10-20 cm across, and floating above the water surface. They have long, spongy and bulbous stalk.
**Sustainability**: In ecology, sustainability is how biological systems endure and remain diverse and productive. Long-lived and health wetlands and forests are examples of sustainability biological systems. The organizing principles for sustainability, is sustainable development, which includes four interconnected domains, ecology, economic, politics and culture. Sustainability science is the study of the concepts of sustainable development and environmental science.

**Ecosystem**: Is a community of living organisms (plants, animals and microbes) in conjunction with the non living components of their environment (things like air, water and mineral soil.) interacting together through nutrient cycle and energy flows. An ecosystem are defined by networks of interaction among organisms and between organisms and their environment. They can be of any size and usually encompass specific, limited space. (although some scientists say that the entire planet is an ecosystem)

**Remote Sensing**: Is the acquisition of information about an object or phenomenon without making physical contact with the object and thus in contrast to in situ observation. In modern usage the term generally refers to the use of the aerial sensor technologies to detect and classify objects on Earth (both on the surface on the atmosphere and ocean). It may be split into active remote sensing, when a signal is first omitted from aircraft or satellites) or passive (e.g Sunlight) when information is merely recorded.

**Fishing industry**: Includes any industry or activity concerned with taking, culturing, processing, preserving, storing, transporting, marketing and selling fish or fish products.

**Proliferation**: To grow or multiply by rapidly producing tissues, parts, cells or off springs. Excessive spread or increase.

**Harbor**: Is a body of water were ships, boats and barges seek shelter from stormy weather or else are stored for future use.
CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

The spread of invasive alien species is neither easy to manage nor easy to reverse, threatening not only biodiversity but also economic development and human wellbeing (UNEP, 2012). Native to the Amazon Basin in South America water hyacinth has emerged as a major weed in more than 50 countries in the tropical and subtropical regions of the world with profuse and permanent impacts (Patel 2012, Téllez et al, 2008, Shanab et al, 2010, Villamagna and Murphy 2010). Worryingly, climate change may allow the spread of water hyacinth to higher latitudes (Patel, 2012). Intensified monitoring, mitigation and management measures are needed to keep water hyacinth at unproblematic levels.

It is widely reported that water hyacinth is indigenous to Brazil having first been described from wild plants collected from Francisco River in 1824. In Africa it was first reported in Egypt between 1879 and 1893. By the early 1990s it had spread to virtually every country in the continent (Makhanu, 1997).

It was first reported in the Ugandan portion of Lake Victoria in 1990 (Thompson, 1991). It is believed that it entered the lake in 1989 via the Kagera River, which has its mouth in the Ugandan portion of the lake (Muli, 1996). It is not exactly known when it entered Winam Gulf.

Water hyacinth (*Eichhornia crassipes*) is a freshwater weed species. It is a free floating plant and draws all its nutrients directly from water. Currents and wind help in its distribution and dispersal. It comprises 95% water and 5% per cent dry matter of which 50% is silica, 30% potassium, 15% nitrogen and 5% protein (Makhanu, 1997). It has been known to thrive well in nutrient-enriched fresh waters in tropical climatic zones. For this purpose it has been used in wastewater treatment facilities. The weed is mainly found in inshore and shallow areas to which it is swept by currents and sometimes in patchy offshore areas. It spreads fast in shallow (< 6m)
bays and inlets with mud bed surfaces. Lake Victoria's tropical location, shallow depth and nutrient enrichment provide favorable conditions for its proliferation (Mitchell, 1976).

Water hyacinth has limited beneficial uses. It cannot be used as a livestock feed because it contains too much silica, calcium oxalate, potassium and too little protein. It cannot be directly used as a fertilizer because its C:N ratio is too high necessitating addition of N-fertilizer (Makhanu, 1997).

Its economic significance stems from its potential to produce negative consequences for the habitat quality of water bodies. The 'mats' of aquatic plants reduce dissolved oxygen by restricting the exchange of oxygen across the air/water interface. They also affect wind-driven water movement and impede mixing of oxygen-rich surface water (Smith-Rogers, 1999). It also generates large amounts of organic matter. As the organic matter decomposes, biological oxygen demand increases and water quality deteriorates. The oxygen can be reduced to such low levels that it leads to massive fish kills due to oxygen depletion in the water column (Ochumba and Kibaara, 1989). This results in loss of aquatic biodiversity (Muli, 1996).

In shallow lakes and where plant production is great, complete deoxygenation of the sediments and deeper water can occur. Such conditions are not compatible for the survival of fishes and invertebrates. Moreover, under anoxic conditions, ammonia, iron, manganese and hydrogen sulphide concentrations can rise to levels deleterious to biota. In addition, phosphate and ammonium are released into the water from anoxic sediments, further enriching the ecosystem (International Development Research Centre, 2000).

The plant can also block waterways, such as Kisumu harbor and fish landing beaches and piers and prevent boats from docking. The plant can clog irrigation canals and electricity generating turbines and its presence can be a general risk to public health.
2.2 WATER HYACINTH AND THE FISHING INDUSTRY

The fisheries sub-sector plays an important role in Kenyan economy. The sector provides employment to over 500,000 Kenyans engaged in fish production and fish related enterprises. The fisheries sub-sector is however unable to realize its full potential due to among other factors over-reliance to capture fisheries and environmental degradation (Wafula et al, 2005).

Water hyacinth affects access to fishing grounds and fish catch-ability (Kateregga & Sterner, 2009). Reports from around the world indicate some villages where people have died from heavy water hyacinth infestations; notably through starvation because they could not reach food sources and protein deficiency resulting from unavailability of fish (Navarro & Phiri, 2000). Water hyacinth causes severe problems to fishermen in the riparian communities. When weed infestation is present, access to fishing sites become difficult for riparian communities which rely solely on fishing as their main economic activity (Munjigni, 2001). This leads to increase in their expenditure on fuel for engine boats and further increase in the cost of the meager quantities of fish they catch, for the society as a whole. There is often loss of fishing gears when nets or lines become tangled in the root systems of the weed. All these lead to reduction in fish catch and subsequent loss of livelihood. Center et al. (2002) reported that water hyacinth invasions reduce available light for submerged plants hence depleting oxygen, alters the composition of invertebrate communities, impacts fisheries, displaces native plants and wildlife, and increases sediment loading.

Information from the Fisheries Department, Kenya according to Mailu (2001) indicated that there was a 28% increase in total annual fish catches between 1986–1991 and 1991–1997, from 133,097 tonnes to 169,890 tonnes. There was an increase in all species of fish caught except Oreochromis, Clarias and Mormyrus, which showed declines of 14, 37 and 59%, respectively, over the same period. These declines may have been associated with the inability of fishermen to access the fishing grounds for those species because of water hyacinth infestation. Generally therefore, as a result of water hyacinth infestation, accessibility to land and water has been hindered, resulting in reduced fish catches, especially of tilapia and mudfish which are found mainly along the shores. Fisherfolk, however, reported increased fish catches from suitable
breeding grounds provided by water hyacinth e.g. tilapia, synodontis, propterus and labeo. A reduced fish catch would have an adverse effect on the quality of life of the communities around the lake and consequently affect sustainable development in the region.

Water hyacinth can greatly affect a fishery if it induces changes in fish community composition, or if catch-ability of harvested species is changed. Diversity in fish stocks is often affected with some benefiting and others suffering from the proliferation of water hyacinth (Calvert, 2002). In Lake Victoria, fish catch rates decreased because water hyacinth mats blocked access to fishing grounds, delayed access to markets, and increased fishing costs (effort and materials) (Kateregga & Sterner, 2009). Mats also blocked breeding, nursery, and feeding grounds for economically important species, such as tilapia and Nile perch in Lake Victoria (Twongo & Howard, 1998). It is interesting to note that decreased catch-ability of certain overfished species can lead to increased fishery stocks (Kateregga & Sterner, 2009) that in the long-run could benefit a fishery and human society.

The water hyacinth is an important fish feed. The Chinese grass carp is a fast growing fish which eats aquatic plants. It grows at a tremendous rate and reaches sizes of up to 32 kg (National Academy of Science (NAS), 1979). It can eat both submerged and floating plants. The fish can be used for weed control and will eat up to 18 – 40% of its own body weight in a single day (Gopal, 1987). Also, dehydrated water hyacinth has been added to the diet of channel catfish fingerlings to increase their growth, hence used indirectly to feed fish (Gopal, 1987). According to Gopal, 1987 decay of water hyacinth after chemical control also releases nutrients which promote the growth of phytoplankton with subsequent increases in fish yield.

2.3 FISHING PRODUCTION

The infestation of water bodies by water hyacinth resulted in a reduction in levels of fish production and species composition of the catch. The fish caught is of poor quality and the cost of operation and maintenance has increased resulting to lower incomes to the fishermen and escalating prices to consumers. Large mats of the weed also sweep away the entangle fleets of nets and poses as a major obstruction to fisheries operation (KARI/LVEMP, 2004)
The vegetation may be good for the ecosystem as fish can reproduce and grow to full size before they are harvested. The weed and its impacts affect 44,000 fishermen and their families, who depend on the lake directly. The vegetation covers hinders of the lake and has raised concerns. Experts say haplochromis, locally known as “fulu” was a staple food and an indicator of biodiversity in the lake four decades ago. The species was believed to be extinct after the colonial government introduced Nile perch, which fed on them, in 1960s. Nile perch has since been overfished (Nkuba, 1998). The five-centimeter bony fish is a delicacy for its nutritional Value. Known as ‘furu’ in Uganda and Tanzania it comprised more than 70% of fish in the Lake (The Standard Newspaper, 2008).

In Kenya, Information from the fisheries department indicated that there was an increase of the total annual fish catches from 133,097 tons in 1986-1990 to 169,890 tons in (1991-1997). There was an increase in fish caught in all aspects expect oveochrimics, larus and marymyrus hich indicated that at 14%, 37% and 59% decline over the same period. It should be noted that whilst hyacinth plants provide food for fish in some measures the deoxygenated problem associated with the excessive growth causes more serious interference with fisheries (KARI/LVEMP, 1999)

2.4 IMPACTS OF WATER HYACITH

2.4.1 Destruction of biodiversity

Today, biological alien invasions are a major driver of biodiversity loss worldwide, (Pyšek and Richardson 2010, Vila et al. 2011). Water hyacinth is challenging the ecological stability of freshwater water bodies (Khanna et al, 2011, Gichuki et al, 2012), out-competing all other species growing in the vicinity, posing a threat to aquatic biodiversity (Patel, 2012). Besides suppressing the growth of native plants and negatively affecting microbes, water hyacinth prevents the growth and abundance of phytoplankton under large mats, ultimately affecting fisheries (Gichuki et al, 2012, Villamagna and Murphy, 2010).
2.4.2 Oxygen depletion and reduced water quality

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

2.4.3 Breeding ground for pests and vectors

Floating mats of water hyacinth support organisms that are detrimental to human health. The ability of its mass of fibrous, free-floating roots and semi-submerged leaves and stems to decrease water currents increases breeding habitat for the malaria causing anopheles mosquito as evidenced in Lake Victoria (Minakawa et al. 2008). Mansonioiides mosquitoes, the vectors of human lymphatic filariasis causing nematode Brugia, breed on this weed (Chandra et al. 2006, Varshney et al, 2008). Snails serving as vector for the parasite of Schistosomiasis (Bilharzia) reside in the tangled weed mat (Borokini and Babalola, 2012). Water hyacinth has also been implicated in harboring the causative agent for cholera. For example, from 1994 to 2008, Nyanza Province in Kenya, which borders Lake Victoria accounted for a larger proportion of cholera cases than expected given its population size (38.7% of cholera cases versus 15.3% of national population). Yearly water hyacinth coverage on the Kenyan section of the lake was positively associated with the number of cholera cases reported in the Province (Feikin et al, 2010). At the local level increased incidences of crocodile attacks have been attributed to the heavy infestation of the weed which provides cover to the reptiles and poisonous snakes (Patel 2012, Ndimele et al, 2011).
2.4.4 Blockage of waterways hampering agriculture, fisheries, recreation and hydropower

Water hyacinth often clogs waterways due to its rapid reproduction and propagation rate. The dense mats disrupt socioeconomic and subsistence activities (ship and boat navigation, restricted access to water for recreation, fisheries, and tourism) if waterways are blocked or water pipes clogged (Ndimele et al., 2011, Patel 2012). The floating mats may limit access to breeding, nursery and feeding grounds for some economically important fish species (Villamagna and Murphy, 2010). In Lake Victoria, fish catch rates on the Kenyan section decreased by 45% because water hyacinth mats blocked access to fishing grounds, delayed access to markets and increased costs (effort and materials) of fishing (Kateregga and Sterner, 2009).

2.5 SOCIO-ECONOMIC IMPACTS OF WATER HYACINTH

Water hyacinth infestation as from 1992, when it was first seen in Lake Victoria, the Winam Gulf, it has caused a lot of impacts to the community livelihoods. The weed’s infestation has several effects which is associated with which has reduced the fishermen’s performance towards fishing production; these are things like diseases, reduced water quality, loss of recreation areas, reduction in transportation among other effects. Since the community depends on Lake Victoria for their sources of income.

Most water bodies are a source food, energy, drinking, Irrigation, transportation and repositories for human agriculture and industrial wastes. Most of these water bodies are infested with water hyacinth which is considered the most noxious of all aquatic weeds and ranked as 8th among the world’s weed (Varnshney, 1976).

2.6 THEORETICAL FRAMEWORK OF THE STUDY

The study was based on the Opportunity-Based Entrepreneurship theory by (Drucker, 1985). The theory asserts that entrepreneurs do not cause change but exploit the opportunities that change creates (change in technology, consumer preferences etc.) (Drucker, 1985). The entrepreneur always searches for change, responds to it, and exploits it as an opportunity. What is apparent in
Drucker’s opportunity construct is that entrepreneurs have an eye more for possibilities created by change than the problems.

Stevenson (1990) extends Drucker’s opportunity-based construct to include resourcefulness. He concludes that the hub of entrepreneurial management is the pursuit of opportunity without regard to resources currently controlled. Entrepreneurs identify business opportunities to create and deliver value for stakeholders in prospective ventures. While elements of opportunities may be recognized, opportunities are made, not found. Careful investigation of and sensitivity to market needs and as well as an ability to spot suboptimal deployment of resources may help an entrepreneur begin to develop an opportunity (which may or may not result in the formation of a business). But opportunity development also involves entrepreneurs’ creative work. Therefore, “opportunity development” rather than “opportunity recognition,” was the focus of this study. In this study, the residents around the Winam Gulf, in spite of the problems created by the presence of the water hyacinth on the surface of Lake Victoria, some take advantage of the entrepreneurial opportunities created by its infestation while others premise their entrepreneurial activities on the absence of the water hyacinth.

2.7 CONCEPTUAL FRAMEWORK OF THE STUDY

The conceptual framework (Figure 2.1) shows the relationship between the independent variable (water hyacinth) and the dependent variables (economic activities). It was conceptualized that when water hyacinth covers the water surface, extraction of water from the lake is hampered leading to harvesting of lower volumes of water than the operational capacity of the water treatment plant. The hyacinth also affects the chemical composition of the water. The low water volumes reduce the water business activities that affecting the livelihoods of the people who depend on the business for their livelihoods.

With regard to the fishing industry, it was conceptualized that the coverage of the water by the water hyacinth impedes fishing thus reducing the number of fish caught. The water hyacinth
entangles the fishing equipment, making fishing difficult. However, on a positive front, the water hyacinth may be eaten by the fish as feed and therefore increase the fish population.

When the hyacinth is harvested, it may be used as raw material in the weaving industry for making some forms of furniture, baskets, ropes and other craft that are sold to earn income. Some of the items made from the hyacinth may attract tourists thus promoting tourist activities. On the other hand, the water hyacinth may block the water ways thus affecting navigation of boats, which greatly affects tourism and other recreational activities.

The interaction between the water hyacinth and the economic activities may be moderated by seasonal movements of the water hyacinth which either opens up the water or covers the water surface thus impeding any activities on the surface. The level of infestation of the hyacinth also determines the level of exposure of the water surface to allow for both biological activities and other human activities in the water. When the water hyacinth is harvested as raw material for various basketry and craft products, water surface is opened up to allow for the mentioned processes to take place. On the other hand, the toxicity of the water may influence all the biological processes, production and use of the water.
Figure 2.1: The conceptual framework of the study.

**Dependent Variables**
- Transportation Industry
  - Blocks access of boats
  - Cost of transportation
- Water supply
  - Water vending/cost
  - Volume of water produced for domestic use
  - Water quality
- Fishing industry
  - Volume or weight of fish harvested
  - Retail business
- Benefits
  - Furniture
  - Basketry
  - Craftwork
- Tourism activities
  - Boat riding/sailing
  - Recreation
  - Artwork business

**Moderating variables**
- Movement and growth cycles of the hyacinth
- Level of infestation of the hyacinth
- Harvesting of the hyacinth
- Toxicity of the hyacinth to Water

**Independent Variable**
- Water Hyacinth
2.8 Gaps in Literature Reviewed

In the review of related literature, it was found that a lot of studies had been done on the environmental impacts of the water hyacinth mainly concentrating on the water quality component, but no studies had been done to establish the effects of this aquatic weed on the economic activities of the community around the lake who derive their livelihood from the fresh water lake. Water quality studies were mainly conducted by Lake Victoria Environmental Management Project Phase I (LVEMP I).
CHAPTER 3: STUDY AREA

3.0 INTRODUCTION

This chapter provides the back ground information of Kisumu County which is located on the southern part of the Winam Gulf. It gives information on the location as shown in figure 3.1, its climate. It also gives an overview of the socio-economic activities, population profile and how each of these items relates to water hyacinth.

Figure: 3.1.Location of Kisumu County in Kenya
3.1 Location and Extent

**Kisumu County** is one of the new devolved counties of Kenya. Its borders follow those of the original Kisumu District, one of the former administrative Districts of the former Nyanza Province in western Kenya. Its headquarters is Kisumu City. It has a population of 968,909 (according to the 2009 National Census). The land area of Kisumu County totals 2085.9 km².

Kisumu County's neighbours are Siaya County to the West Vihiga County to the North, Nandi County to the North East and Kericho County to the East. Its neighbour to the South is Nyamira County and Homa Bay County is to the South West. The county has a shoreline on Lake Victoria, occupying northern, western and a part of the southern shores of the Winam Gulf.

Kisumu County stretches from the Nandi escarpment in the East to the Kano Plains in the middle all the way to the hills of the West. The Kano Plain is perhaps its most famous feature, sporting black cotton soil that is very fertile. The county has several inselbergs, mostly in the Kisian Area. Several rock outcrops also exist, the most famous of them being Kit Mikayi in Seme Sub-county.

Figure 3.2: (a) Localization of the Winam Gulf with respect to Lake Victoria and the riparian countries Kenya, Uganda and Tanzania; (b) Kisumu harbour invaded by water hyacinth; (c) floating water hyacinth.
Kit Mikayi consists of several rocks piled onto each other, with several caves inside. Kit Mikayi is one of the spectacular and large piles of rock in the county.

3.2 Physiography and drainage

Kisumu County is characterized by a gently undulating landscape, consisting of broad, flat-topped ridges and long and gentle valley slopes. Altitudes range from about 1140m along the lake Victoria shores in the south and about 1400m asl in the northern area. In the investigated area, the altitude is ranging from 1350m to 1462 m asl. The investigated site lies within an area that experiences heavy rainfall over the inland areas but the yearly average drops sharply on the edge of Lake Victoria.

3.3 Geology and Soil

Kisumu County forms part of the built up out of Precambrian rocks. Since the time those rocks were formed and the area emerged above sea level, for a long time no major geological activities took place. Until the Miocene, when major tectonic activities started to affect the area. The same forces which initiated the formation of the East African Rift valley in Kenya had only minor influence in this part of the country.

Rocks in the study area range from early Precambrian to Quaternary. The Precambrian rocks which include mainly volcanic series. The main geological feature in the area is the Kavirondo Rift. This rift branches from the main north-south orient Kenya Rift Valley system, trending east-west and northeast to southwest towards Lake Victoria. Rocks in Kisumu North District can be divided into three well-defined groups, based on their relative age and lithology:

- Recent deposits.
- Tertiary volcanic rocks
- Kavirondian system
- Intrusives
- Precambrian Nyanzian System rocks.
3.4 Climate and Vegetation

The climate of the whole county is modified by the presence of the lake. The county has an annual relief rainfall that ranges between 1200 mm and 1300 mm in different sectors. The rain mainly falls in two seasons. Kisumu is known for its thunderstorms, which are the major type of precipitation and normally occur in mid-afternoon during the rainy season. Kisumu is warm throughout the year with a mean annual temperature of 23 °C. The temperature ranges between 20 °C and 35 °C but seldom falls below 19 °C. The humidity is relatively high throughout the year.

The main types of woody vegetation are Savanna woodland (Acacia, Albizzia and Butyrospermum). The main species of herbaceous vegetation is Cymbopogon, Hyparrhenia, Londetia and Cypris papyrus. The main kinds of crop are Maize, cotton, sisal, tobacco, beans, sugar cane, coffee, sorghum, millet, wheat and root crops (cassava, etc.). The level of fertilizer application on the crops fields is light. There is a decrease in the forest area of Kisumu due to the high population and the excessive cultivation.

3.4.1 Agro-ecological zones

The key livelihood zones are Marginal mixed farming, mixed farming and Fisheries. Ecologically the District spreads across agro-ecological zone UM3, LM1 to LM4. The altitude range is 990 -1470 meters above sea level. The District also boarders Kisumu East District to the east, Bondo District to the west, Lake Victoria to the south and Vihiga District to the north.

3.5 The economic set up

3.5.1 Agriculture

As earlier stated, 62.10% of all households in Kisumu County depend on crop farming as a source of income. With a county household density of 107.8 per sq. km., much of this agricultural activity is practiced on small parcels of land. Continued pressure and subsequently sub-division of land, much like in the rest of the country has led to environmental degradation.
that has been made worse by global warming, causing parts of the county to experience food shortages at various times. Perennial flooding in Nyando and other parts continues to affect food production. The main (cash and food) crops grown include beans, maize, tea, sorghum, finger millet, potatoes, pyrethrum, sugarcane, ground-nuts, kales and cotton. Rice is grown under 2,000 ha. at the Ahero Irrigation Scheme in Nyando Constituency. The water to the scheme is fed by gravity from River Nyando. Rice is also grown on a smaller scale at the Kabonyo Irrigation Scheme in Nyando Constituency.

3.5.2 Industry

Kisumu city and the surrounding areas have several light industries. These include textiles, molasses, fish processing plants and agricultural produce processors. Kisumu has 3 sugar factories, at Chemelil, Muhoroni and Kibos. There are plans for a fourth mill. Several backyard industries also thrive in the county, including tailoring, making of handicrafts and boat-building.

3.6 Infrastructure and Communications

Mobile phone penetration is high, and the coverage by the major service providers (Safaricom, Airtel, Orange and Yu) is basically reliable. The post offices in the county still function. Courier services also exist, providing quick ways of sending parcels and letters outside the county.

3.6.1 Transport

Kisumu County has several paved roads, the major one being the Nairobi-Bondo road, which has a branch at Kisian heading to Busia. Important roads are paved with asphalt. County roads are mostly murram but provide all weather movement all year. Public transport services are provided by matatus and buses either operating singly or as parts of franchises and companies. Bicycle and motorcycle boda-bodas also exist in significant quantities for short distance travel.

The city of Kisumu was founded as a terminal for the railway, and therefore has an important railway station. The narrow gauge railway moves both passengers and cargo, linking Kisumu
with other cities and towns along the line. The new national government has pledged to build a new modern metro network for the city.

Water transport on the lake is provided mostly by private operators in wooden boats with outboard engines, although a ferry service exists. The services connect towns on the shores and also help in crossing the lake. They also link the county with the other three lakeside counties and the countries of Tanzania and Uganda. The port of Kisumu is very inactive at the moment but has the potential to become a regional centre of lake transport and a gateway for Kenya into the rest of the African Great Lakes region.

Kisumu International Airport has been upgraded and now has the potential to be an Centerport for the entire region. Schedule flights land from Nairobi, Mombasa and several cities in neighboring countries.

3.6.2 Tourism

Kisumu County is fast developing into a major tourist destination in the Western Tourism Circuit of Kenya. Replete with great scenery and diversity concentrated within a relatively small area, Kisumu County's tourism sector is expected to experience a major boom.

Features like the shoreline of Lake Victoria, Kit Mikayi and other rocks of similar stature, Ndere Island National Park (which hosts an amazing variety of wildlife within a confined area), the God Mesa viewpoint in Nyabondo (from which one has a panoramic view of the Nyando Plains and Lake Victoria in the distance, and the inselbergs around the Kisian area provide a great attraction for tourists. The Kisumu Museum and the Impala Park provide further tourist attractions. Kisumu is touted to have one of the best sunsets in the world, and arguably the best in Kenya, with the sun sinking into the horizon over the lake turning the water into many hues, a spectacle that continues to drive up tourist numbers into the county.
The Kisumu International Airport now has the potential to deliver international tourists directly into the county, and it is expected that this will be a major boon for the industry in the county. Tourist infrastructure, like hotels and lodges, are now springing up in many places.

3.7 POPULATION

County is relatively densely populated compared with the rest of Kenya. The 2009 census showed that the county had a population of 968,909. With an area of 2,085.9 km2, Kisumu County has a population density of 460 per square kilometres, comparable to that of the entire South Korea. The vast majority of the people belong to the Luo ethnic community, the third largest tribe in Kenya and one of the largest in East Africa. There are also small numbers of minorities from the other ethnic communities of Kenya, predominantly the Luhya. Indians came with the railway construction, and now form a substantial Indian community in Kisumu city. The dominant language is Dholuo, but Kiswahili and English are also spoken by a majority of the population for non-domestic purposes.

The people of Kisumu eat a lot of fish prepared in a variety of ways. This high consumption has sometimes been touted as one of the causes of the generally high IQ levels in the region, and the eating of fish has become popular all over Kenya as a result. This is usually accompanied by ugali, a dish made of maize flour which can also be mixed with other grains, mostly millet, sorghum and/or cassava. Vegetables are also eaten.
CHAPTER 4: RESEARCH METHODOLOGY

4.0 INTRODUCTION

This chapter discusses the design and the methodology of the study focusing on method of data collection, analysis and presentation.

4.1 Materials and Method

Data Acquisition and Processing

A time-series of MODIS multispectral images covering a period of 10 years (from 26 February 2000 to 15 January 2010) equivalent to 3605 days of data acquisition, has been used to monitor with at least weekly frequency the floating vegetation extension over the water surface of the Winam Gulf. A preliminary analysis (Laneve et al., 2010) carried out on Landsat images showed that the number of available data is insufficient for revealing accurately the time when the abnormal plants proliferation starts or the peak period or the decreasing phase.

To this end the TERRA MODIS spectral bands 1 (620–670 nm) and 2 (841–876 nm) with a 250 m spatial resolution have been used in the study to distinguish the floating vegetation from water and land by calculating the NDVI. In addition, AQUA MODIS spectral bands 1–4, with a 500 m spatial resolution (MYD02HKM, level 1B, collection 5), were also used to analyze the optical properties of the water column to retrieve the water constituent concentrations (Chl a, TSM, CDOM), in order to establish a correlation between aquatic weed proliferation and water quality parameters, if any. The time availability of these data ranges from 2002 to 2009. Furthermore, AQUA MODIS clouds mask (MYD35 L2 – level 2) was used to automatically remove MODIS images with cloud cover greater than 10% of the lake surface defined by the coastline of the Winam Gulf.

All MODIS standard products were ordered directly from the LAADS website (http://ladsweb.nascom.nasa.gov/data/) and retrieved from the LAADS ftp site (ftp://ladsweb.nascom.nasa.gov/). For this study, additional data were analyzed to determine if
other factors may have contributed to the fast growth of the macrophytes. In particular, we have taken into account the averages of the monthly rainfall and temperatures recorded at the meteorological station of Kisumu (courtesy of the Kenya Meteorological Department)

4.2 Methodology

Changes in the vegetation seasonal behavior can be assessed by means of the NDVI, derived from time-series of MODIS imagery or from other satellite sensors (e.g. NOAA/AVHRR, SPOT/VEGETATION, etc., Ahl et al., 2006; Jacquin et al., 2010; Zhang et al., 2003). The NDVI is a measure of the amount and health conditions of the biomass on the land surface and maps based on this vegetation index are developed to distinguish more easily green vegetation from other not-photo-synthetically active surfaces (Rouse et al., 1974; Tucker, 1979). Indirectly, NDVI was used in the study, to estimate the cumulative effect of rainfall on vegetation over a certain time period, rangeland carrying capacity, crop yields for different crop types, and the quality of the environment as habitat for various animals, pests and diseases. NDVI is calculated by subtracting the red spectral channel from the near-infrared (NIR) spectral channel and dividing their difference by the sum of the two channels. In other words, for MODIS sensor it can be expressed as: \( \text{NDVI} = \frac{\_2 - \_1}{\_2 + \_1} \) where \_1 and \_2 are MODIS red and near-infrared reflectance bands, respectively. NDVI values range from −1.0 to 1.0, with negative values indicating clouds and water, positive values near zero indicating bare soil, and higher positive values of NDVI ranging from sparse vegetation (0.1–0.4) to dense green vegetation.
4.3 Nature and sources of data

The aim of the study was to determine the impacts of water hyacinth on the fishing industry at the Winam Gulf. This was achieved by examining the nature and extent of water hyacinth infestation at the Winam Gulf, this was achieved through using remote sensing data, by acquiring satellite images of different years, with an interval of five years, example 1990, 1995, 2000, 2005, 2010. I used the false color band combination so as to identify the water hyacinth on the lake. Digitize the water hyacinth on the lake by creating a polygon feature using the Arc map software and also identifying my area of interest. Thus I would create a shape file of my area of
interest. Using the arc map software I was be able to calculate the area that has been occupied by water hyacinth at Winam Gulf through the years hence I would be able to determine the spread of water hyacinth. NDVI images was also be used to determine how the water hyacinth has been spreading monthly. To determine impacts of water hyacinth on the fishing industry at the Winam Gulf, was achieved using secondary sources of data collection, such as existing reports and journals to find out the impacts of water hyacinth around the area.

4.4 Secondary data

Data concerning the impacts of water hyacinth was obtained from several sources including books; journals; magazines; reports national District development plan and policy document. This would necessitate visiting the library, among other institutions.

4.5 Method of data analysis and presentation

Various method and techniques of data analysis and presentation was used in order to achieve the purpose and objectives of the study; this include descriptive, qualitative techniques and image interpretation

- In qualitative methods that was used includes: statistical table, maps and other diagrams suitable for such analysis and presentation.

Image interpretation of the satellite images of the study area was also done.
CHAPTER 5: RESULTS AND DISCUSSIONS

5.0 INTRODUCTION

This chapter focuses on data analysis and discussions based on the objectives of the study. The study is based on water hyacinth mapping satellite images such as LANDSAT AND NDVI of different years, to show the spread and pattern of water hyacinth at the Winam Gulf and how the urban areas have contribute to the problem of water hyacinth. The analysis is presented Using statistical tables, line graphs and images.

5.1 HYACINTH MAPPING

Image acquisition

Landsat satellite images were acquired covering the area of interest that is the L Victoria area of the year 2010. The ETM+ images had the same spatial resolution (28.5m). Having a challenge of cloud cover and image availability these were the images acquired.

<table>
<thead>
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<th>Image (Landsat ETM +)</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>p170r60</td>
<td>23rd Dec 2010</td>
</tr>
<tr>
<td>p170r61</td>
<td>3rd July 2011</td>
</tr>
<tr>
<td>p170r62</td>
<td>17th Aug 2010</td>
</tr>
<tr>
<td>p171r60</td>
<td>28th Jan 2010</td>
</tr>
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<td>p171r61</td>
<td>4th Jul 2009</td>
</tr>
<tr>
<td>p171r62</td>
<td>14th Dec 2010</td>
</tr>
</tbody>
</table>

Path = 170; row = 60

Table 1: Scene number and dates of which the Landsat images used for the study where acquired

The other images are Alos images covering the Kenyan area at a resolution of 10m.
5.1.1 Image Processing and Interpretation

Mapping of water hyacinth in Lake Victoria
Mapping of water hyacinth (*Eichorniacrassipes*) involved application of remote sensing techniques and GIS interlaced with computer aided cartography.

5.1.2 Remote Sensing Techniques

Geometric Correction of the Landsat ETM+ Raw Data

Images acquired are usually raw and processing needs to be done to enable interpretation. Therefore raw digital satellite data was geo-rectified to correct geometric distortions arising from sensor geometry, scanner and platform instabilities, earth rotation and earth curvature among others based upon established ground control points. Ground control points (GCPs) were selected at locations distinct on both the imagery and topographic map. Care was taken while establishing the GCPs that they should be as small as a single pixel, contrasting strongly with their background and should not be too large to preclude accurate determination of their location (Campbell, 1996). This was necessary in order to integrate the satellite data with other datasets in a GIS such topographic map sheets of scale 1 50,000 and the Alos image that was already geo-rectified and geo-referenced. All the images were the reprojected to UTM Projection, Zone 37S and WGS 84 Datum.

Construction of False Color Composite Image

Landsat ETM spectral bands were selected and combined in red, green and blue (RGB) color system, to make a false-color composite image. Different spectral combinations of the ETM bands were tried to select the best color composite image to be used for the visual and digital discrimination of the study area. The histogram equalization enhancement techniques were applied to these data to increase the contrast in the images (Schowengerdt, 1983; Mather, 1987 and Lechi, 1988). The optimum band combination was determined cumulative nature of image bands to enhance interpretation (Sabins, 1997).
The image processing technique is applied through a construction of a Landsat ETM false-color composite (FCC) image for the study area constructed by the combination of ETM bands 4, 3 and 2 displayed in red, green and blue respectively. The constructed FCC image has a relatively coarse spatial resolution of 28.5 m. The panchromatic ETM band-8 image of a better resolution of 15 m was used as a pan sharpener. The resulting fused image displayed the spectral characteristics of the multispectral ETM bands (FCC image) were used for interpretation.

**Image Interpretation**

The Landsat ETM+ FCC data for the study area was interpreted based upon image interpretation elements. Raster vectorization was done using GLCN Madcat software. Polygons representing homogenous sites of the hyacinth were identified and marked onto the satellite sensor data as training samples. Eight training areas (containing at least 5-8 pure training pixels) were selected for that particular land cover type.

**GIS and computer aided cartography**

Geographic Information System (GIS) method for integrating both existing and newly collected spatial data was used. GIS post processing to identify, demarcate and map the land use was done in ArcGIS 2010. The same was used to calculate the areas covered by the water hyacinth.
Figure 5.1: A mosaic Landsat of Lake Victoria.

Source: Regional centre for mapping of resources for development
The image above is the Alos mosaic Alos image of Winam Gulf the year 2010.
Figure 5.3: An Alos Image of 2010 of the Winam Gulf, the Red vegetation on the Lake is water hyacinth
Source: Regional centre for mapping of resources for development.

In The satellite image above the red vegetation on the Lake is the water hyacinth of which it has covered a wide area of the Winam Gulf, from the above image the area covered by water hyacinth is 37,000 Hectors, the image shows how water hyacinth has become a major problem affecting transportation activities around the Winam Gulf making it difficult for the fishermen to navigate around the lake, thus hindering the fishing activities, since the fishermen get stuck with their boats hence making it difficult for them to fish.
5.1.3 The Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI) technique was applied in this study to map spatial and temporal changes in water hyacinth cover in Winam Gulf using ERDAS Imagine 9.3. The NDVI is widely used as a measure for photo-autotrophs (plants and algae), and is excellent for detecting presence of vegetation in many environments (Ma et al. 2007; Kiage and Walker 2009; Wilson and Sader 2002; Walker et al. 2009; Raynolds et al. 2006; Anyamba et al. 2001). It is computed from reflectance in the red (RR) and nearinfrared (RNIR) portion of the electromagnetic spectrum as follows: 

\[
\text{NDVI} = \frac{\text{RNIR} - \text{RR}}{\text{RNIR} + \text{RR}} 
\]

For the MODIS Aqua/Terra sensor, the red band is band 1 (620–670 nm, central wavelength 645 nm) and the NIR band is band 2 (841–876 nm, central wavelength 859 nm). A number of studies (e.g. Kiage and Walker 2009; Jiang and Huete 2010; Tian et al. 2010; Anyamba et al. 2001) have shown that NDVI can be a sensitive indicator of presence or absence of vegetation in both aquatic and terrestrial environments.

The excellent efficacy of the NDVI for detecting vegetation is attributed to the fact that chlorophyll a in plants absorb red light for photosynthesis and reflect highly in the near infrared wavelengths because of scattering caused by internal leaf structure. In the absence of photo-autotrophs in water bodies, NDVI yields mostly negative values. Therefore, positive NDVI indicate the presence of vegetation and can be a good tool for mapping floating vegetation in lakes. Kiage and Walker (2009) demonstrated that the technique of using NDVI provides an effective means of detecting and mapping floating vegetation in a eutrophic lake. The NDVI ranges between −1 and 1, with values above zero indicating presence of vegetation and those below zero indicating absence of vegetation. Bare grounds typically have values between 0 and 0.1; the latter is normally considered the threshold for vegetation (Kiage et al. 2007). In this study, surface areas in Winam Gulf that had NDVI values above 0.1 were depicted as floating vegetation mats because most plants typically have NDVI values above 0.1 (Kiage and Walker 2009; Ma et al. 2007).
5.1.4 RESULTS AND DISCUSSIONS

The NDVI from medium spatial resolution channels (250–500 m) of Aqua/MODIS showed great promise for mapping water hyacinth blooms in the Winam Gulf of Lake Victoria. The major output of this study was the compilation of time-series NDVI maps for the Winam Gulf of Lake Victoria showing the dynamics of the water hyacinth over an 11-year period (1999–2010). The spatial extent of water hyacinth in the Winam Gulf during the 11-year period is summarized in Figs. 5.5 and 5.6. The NDVI shows that the highest quantity of water hyacinth in Winam Gulf occurred in July 2010 when 35,306 ha or approximately 26% of the lake was covered by the weed (Fig. 5.6). The weed occupied large sections of Homa Bay on the southern part of the gulf as well as most of the other sheltered bays including the port of Kisumu (Fig. 5.5). Other significant hyacinth blooms in Lake Victoria occurred in 2003, 2006, 2007, 2008 and 2009 (Fig. 5.5, 5.6). Rainfall data for Kisumu station, which is located on the shores of Winam Gulf, shows that between 1997 and 2009 the total rainfall during the short-rains season (Oct–Dec) ranged
from 179 to 823 mm. High amounts of rainfall during that period were experienced in 1997, 2002, 2004, 2006, 2008, and 2009, all with totals well-above 200 mm, which is the mean total for the short-rains season for the station. The increased spatial coverage of water hyacinth in 1998, 2003, 2006, 2007, 2008 and 2009 appear to coincide largely with periods of increased rainfall during the short rains.
Figure 5.5. A time series of NDVI images analyzed from MODIS data acquired on (a) 17 December 2001 (b) 7 December 2002 (c) 25 December 2003 (d) 26 December 2004 (e) 17 December 2005 (f) 9 December 2006 (g) 18 December 2007 (h) 13 December 2008, and (i) 13 July 2010. The location of the main urban areas around Winam Gulf are marked by white squares and labeled as shown below.

Figure 5.6: Hectares of water hyacinth in Winam Gulf between 1997 and 2010. The data are based on largely on analysis of satellite imagery. The grey bars indicate the duration of El Nino events based on data derived from NOAA and the Climate Research Unit, University of East Anglia.

**5.1.5 Results and discussion**

The analysis based on MODIS imagery dataset makes it possible to highlight the trend of the floating vegetation growth (see Fig 5.9) within the Winam Gulf, in the time range from March 2000 to January 2010. By analyzing the graph shown in Fig. 5.9, we can see that before October 2006, the growth rate remains relatively weak, with a cycle in accordance with the local climatic conditions; in fact, the growth cycle of the floating vegetation is correlated to the two rainy seasons (long and short rainy season, March–May and November, respectively) characterizing this area. In particular, during the years 2002–2004 the phenomenon of the weeds proliferation seems almost absent. However, during 2005 and 2006 the phenomenon shows some signs of
resurgence. After October 2006, the proliferation of the floating vegetation exhibits an abnormal growth rate. Indeed, during the abnormal growth cycle, it is possible to detect when the weeds proliferation becomes very sudden.

Figure 5.7: Temporal comparison between the floating vegetation evolution and rainfall, for the decade 2000–2009.

The analysis based on MODIS imagery dataset make it possible to highlight the trend of the floating vegetation growth (see Fig.5.7) above within the Winam Gulf, in the time range from March 2000 to January 2010. By analyzing the graph shown in Fig.5.7, we can see that before October 2006, the growth rate remains relatively weak, with a cycle in accordance with the local climatic conditions; in fact, the growth cycle of the floating vegetation is correlated to the two rainy seasons (long and short rainy season, March–May and November, respectively) characterizing this area. In particular, during the years 2002–2004 the phenomenon of the weeds proliferation seems almost absent. However, during 2005 and 2006 the phenomenon shows some signs of resurgence. After October 2006, the proliferation of the floating vegetation exhibits an abnormal growth rate. Indeed, during the abnormal growth cycle, it is possible to detect when the weeds proliferation becomes very sudden. The floating vegetation maps based on NDVI values provide an accurate temporal vision of the weeds evolution with a time resolution of at least half-week. The time sequence of this maps, shown in Fig.5.8, highlights the rapid growth of the floating weeds occurred from March to April 2007, when the weed surface increased from about 40 km2 to over 400 km2 (about 33% of the Winam Gulf surface). This event can also be
expressed as FVI values, in this case equivalent to 0.33. It is also interesting to note that this rapid growth is preceded (2–3 weeks) by an increase of sparse/submerged vegetation. This event reaches its peak, in terms of surface extent, in April 2007 and ends around January–February 2008 (see Fig.5.7).

This abnormal proliferation may be related to the unusual heavy rainfall that occurred in Kenya at the end of the 2006, swelling the rivers that flow into the Winam Gulf. As a matter of fact, in the time range 2000–2009, the Kisumu meteorological station recorded that during November and December 2006 the rainfall was 346 and 284 mm, respectively. The first value is the highest value of this decade and both values were 2.5 times larger than the ten-year average. However, this meteorological trend does not continue in 2007, according to the meteorological data recorded at the Kisumu station, even if the rainfall pattern is very different from the averaged behaviour of the last ten years. Unfortunately, the rainfall data from other stations (Eldoret, Kakamega, Kericho, etc.) inside the Kenyan portion of the Lake Victoria basin were not available; therefore it was not possible to assess the effective rain amount in the areas surrounding the Winam Gulf.

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<td>158.8</td>
<td>92.0</td>
<td>82.6</td>
<td>100.6</td>
<td>27.9</td>
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<td>114.2</td>
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<td>36.2</td>
<td>35.0</td>
<td>32.9</td>
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<td>109.5</td>
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<td>164.6</td>
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<td>129.8</td>
<td>306.8</td>
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<td>133.9</td>
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<td>December</td>
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<td>62.2</td>
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<td>5.4</td>
<td>284.0</td>
<td>59.1</td>
<td>37.7</td>
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<td>111.9</td>
<td>101</td>
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Table 2: Monthly rainfall (mm) at the meteorological station of Kisumu city (courtesy of the Kenya Meteorological Department).
Figure 5.8: The time sequence covering the period March–April 2007 where the weed proliferation reaches its maximum extension.
Figure 5.9: Map of the weed proliferation hazard on the Winam Gulf; areas with the highest frequency are the bays, gulfs and areas near the coastline; the colour ramp depicts the frequency of the weed occurrence based on the MODIS images.

The map depicted in Figure 5.9, shows the areas with the highest frequency of weeds. They are mainly the bays, gulfs and areas near the coastline, where water circulation is reduced. The cause could be related to the local environmental conditions, shallow and stagnant waters that promote the increase of the nutrients and at the same time the growth and the accumulation of the floating vegetation.

5.2 How urbanization has contributed to the spread of water hyacinth.

Natural resources on the fringes of urban areas always suffer severe depletion and degradation as urban centers create demand for goods and services thus exerting tremendous pressure on fragile ecosystems. The high rate of urbanization therefore rapidly increases the pressure on these
ecosystems. The increasing population and economic growth of cities associated with urbanization create externalities due to the demand for resources and waste disposal (Leitman 2000).

5.2.1 Water Pollution
That fresh water has played a key role in agriculture, industries, and municipalities, among others is highlighted for instance by Mackenzie (2003, p. 314). Whereas most of the world’s fresh water lakes carry natural substances and nutrients, today, in addition to these natural materials, pollutants, e.g., chemicals and excess eroded soil also find their way into the lakes (e.g., Awange and Ong’ang’a 2006). Oceans, home to salt water marine, also face pollution from human-induced activities as witnessed by the BP oil leak at the Gulf of Mexico in 2010. There is need, therefore, to ensure that this vital source of life suffers minimum pollution as possible. Mackenzie (2003, p. 314) defines water pollution as any physical or chemical change in water from both natural and anthropogenic sources that adversely affects the organisms living in it. Water resources undergoes pollution from both point and non-point sources discussed next.

5.2.2 Point and Non-point Sources

Points sources are, e.g., factory outlet pipes and sewage treatment plant outlets whose positions can be accurately mapped. Surface pollutants include those produced from factories and industries, and agricultural activities. During rainy seasons, storm water carries with it chemicals from fertilizers and pesticides from farms, together with other nutrients from the neighboring towns. These materials are either swept into water bodies (rivers, dams, boreholes, etc) through surface runoffs or percolate into the ground to reach groundwater flows, and finally into the rivers.

The rivers eventually pour their contents into the lakes. The consequence of sewage contamination of water quality include outbreak of human diseases and eutrophication problem, which result in the proliferation of algal blooms and undesirable aquatic macrophytes, e.g., water hyacinth, (see e.g., Awange and Ong’ang’a 2006). In some countries such as Kenya, towns empty their sewage and other industrial effluent into the lakes.
Another example of water pollution is presented by the case of Kisumu (Kenya) where pit latrines (Fig.5.10) are in the same locality with boreholes supplying groundwater (Fig. 5.11) thus contaminates the water. Non-point sources are those that are difficult to identify, e.g., pollution from transportation sector and waste from mining operations, agricultural activities, and waste carried by street runoffs and drainage. From the atmosphere, precipitation containing chemical such as sulfur and nitrogen oxides also contaminate water sources. Owing to their dispersive nature, non-point sources are difficult to control and also to map.

For lake Victoria, studies indicate that the high phosphorous and nitrogen loans choking it are attributed to several non-point sources. The most important of these are agriculture, livestock, domestic and industrial effluents. Most of these activities use large amounts of synthetic compounds including fertilizers and pesticides (Kairu, 2001). Although animal manure and domestic wastes contribute about 3,000 and 132 tons of the total, respectively, their nitrogen inputs are estimated at over 40,000 tons per year (Aseto and Onganga 2003, p. 106). This represents more than three times the amount contributed by synthetic fertilizers.

**Figure 5.10:** Pit latrine (*dotted blue on the online digital version*) plotted on a Map of Nyalenda (Kisumu, Kenya). [Source Department of Planning, MCK (Municipality of Kisumu, Kenya) and Regional Center for Mapping of Resources for Development, (2006) in Opande (2008)]
5.2.3 Eutrophication of the Lakes

Mackenzie (2003, p. 318) defines eutrophication as the process of being fed too well. Eutrophication leads to water quality deterioration, taste and odour problems, oxygen depletion, reduced transparency, decline of fisheries, possible fish kills, clogging of waterways and toxic effects on animals and human beings. The phenomenon is a typical result of nutrient imbalances at several levels. The source of nutrients include agricultural activities, which produce a nutrient rich runoff resulting from the leaching of fertilizers and manure, garbage dumps, sewage, and industrial effluent.

![Figure 5.11: Well-water point locations (dotted red on the online digital version) plotted on a Map of Nyalenda (Kisumu, Kenya). [Source Department of Planning, MCK and Regional Center for Mapping of Resources for Development, (2006) in Opande (2008)]](image)

Odada et al. (2004) listed three causes of eutrophication as:

1. Enhanced effluent discharge.
2. Runoff and storm water.
3. Enhanced discharge of solids.
The first two are the most important causes of eutrophication. The *Clean Water Act* 1972 focused on eliminating point source pollutants through regulating discharges from such point-sources. This was achieved by setting effluent limits by which business were required to adhere. By the 1980s, better controlled point-source posed a minor threat to public waters and focus shifted to storm water management. The San Francisco Public Utilities Commission (SFPUC) in its attempt to reduce storm water pollution mapped the city’s storm drain using a hand-held GPS based data collection device that captured the drain’s precise locations and recorded digital notes on their conditions creating a GIS database (Corbley and Stauffer 2006).

### 5.3 Impacts of water hyacinth on the fishing industry.

For several centuries, the Lake has provided a rich variety of resources to the communities living in the riparian Districts. A part from providing a rich source of protein through fisheries, the Lake offers employment opportunities and generates income to thousands of people. The fish industry provides indirect employment to thousands of individuals who supply the various fishing gears and related complimentary goods, services, and those who utilize fish products and by-products. The importance of fishing in the national economies of the three riparian states has grown rapidly as reflected in the growth in foreign exchange earnings from Nile Perch fillet exports to European countries in recent years.
Fishing as the Main Socio-economic Activity in the LCDB

5.3.1 Depletion of Fishes in Lake Victoria: A Historical Perspective

Before the arrival of the Nile Perch, there were over 500 different haplochromines species in a myriad of shapes, colours, and lifestyles. There were insect eaters, algae scrapers, mud biters, leaf choppers, snail crushers, shrimp eaters, baby eaters, fish eaters, scale scrapers, and snail shellers, all of which found a way to live in one giant Lake by finding a different source of food. To the scientists, this variety of diet and habits was simply astounding. Samples of Earth taken from the bottom of the Lake suggest that the Lake may have temporarily but completely dried up 12,000 to 14,000 years ago. If this is true, these hundreds of cichlid species must have evolved from a handful of ancestral species in this same relatively short span of time. So apparently changeable are the cichlids as a species that, if introduced into a new part of the Lake, they could become, for example, specialized feeders on entirely new types of food.

The cichlids showed that adaptation and evolution could occur much more quickly than anybody had thought. There are some species like Cichlids, which supported commercial fishing in the
1960s, but are now extinct. Between 1973 and 1998, the number of fishermen grew by 300%, increasing to 40,000. The number of fishing boats increased by 266% over the same period to reach 15,000. From available data, the biomass and the abundance of Nile Perch decreased from 790,000 tons in 1999 to about 530,000 tons in the year 2001. Most fish processing plants are operating below 50 per cent capacity due decline in fish stock. Most serious, however, are discoveries that currently close to 60% of fish caught in Lake Victoria are immature and below 70 centimeters in size while the initial size of the Nile Perch caught in the Lake is about 1.8 meters long.

5.3.2 RESULTS AND DISCUSSIONS

Table 3: Impact of water hyacinth to the weekly catch in percentage

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<td></td>
<td>(A) Weekly Catch (kg)</td>
<td>Price (ksh/kg)</td>
<td>Weekly Catch (kg)</td>
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<tr>
<td>Nile Perch (Mbuta)</td>
<td>353.4</td>
<td>44.2</td>
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<td>Tilapia (Ngege)</td>
<td>287.9</td>
<td>49.9</td>
<td>14,366.3</td>
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<td>Daga (omena)</td>
<td>1142</td>
<td>30.4</td>
<td>34,716.8</td>
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<td>Mud Fish(kam Ong)</td>
<td>56.4</td>
<td>41.4</td>
<td>2335</td>
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<tr>
<td>Cat fish (mumi)</td>
<td>32.3</td>
<td>53.8</td>
<td>1737.7</td>
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<td>Total</td>
<td>68,776</td>
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Courtesy: Year 2005 KMFRI DATA

From the table above, the fish production was compared before and after water hyacinth infestation. Fish which survives in open water like Nile patch, Tilapia and omena reduced drastically after water hyacinth infestation since the water body has been covered with the weed and on the other hand fish species like Mud fish, Cat fish which hibernates under the weed and in mud increased in production since they found a better surviving ground beneath the water hyacinth. Consequently, impact of water hyacinth on general fish production is estimated as a
reduction of 21.7%. The prices of all fish species considered were significantly different during the pre and post water hyacinth period as shown above.

This is expected in view of the rising inflation hence increasing prices over the period. It may be difficult to isolate the impact of the change in supply of the fish associated with water hyacinth and the general increase in prices due to inflation.

5.3.3 Photos showing water hyacinth infestation at the Winam Gulf from field observations.

Plate 1: fishermen trapped by water hyacinth hindering fishing

Plate 2: Transportation being hindered by water hyacinth, ships getting stuck at the Lake.
Plate 3: Water hyacinth infestation at the Winam Gulf.
5.3.4 Role of Governments in Fisheries Sector

In the preceding sections, we discussed the issue of resource exploitation. But effective resource exploitation requires efficient management in resource utilization. This section addresses the role of governments in the most important resource, the fishing industry. The need for fisheries collaboration in Lake Victoria was realized early in 1928. More recently, the three East African countries collaborated through the support of Food and Agriculture Organization (FAO) Committee for Inland Fisheries of Africa (CIFA), Sub-Committee for Lake Victoria. A Convention for the Establishment of the Lake Victoria Fisheries Organization (LVFO), drafted with FAO assistance, was signed by all three countries in 1994.

The LVFO was intended to promote better management of fisheries on the Lake, co-ordinate fisheries management with conservation and use of other Lake resources, collaborate with existing bodies and programmes dealing with Lake Management, co-ordinate fisheries extension, advice on introduction of non-indigenous animals or plants into the Lake, and disseminate information on Lake Victoria.

The LVFO is currently supported by the European Union through the Lake Victoria Fisheries Research project. Recently, there has been an effort in each of the three East African countries to actively pursue strategies to ensure the sustainable development of fisheries. The following is a discussion of what is being done at the level of the three states collectively, and at the level of one state, Kenya.
CHAPTER 6: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of the findings.

The magnitude of the problems caused by water hyacinth varies not only with the nature of its growth but also according to the importance of water bodies and its use. As mentioned earlier the weed can remain dormant for 35 years and cover vast areas making its impact more disastrous. With regard to Lake Victoria and in particular the study area, the problem caused by water hyacinth infestation can be summarized as follows:

- Impede the movement of boats and steamers for transportation.
- Impair the fishing sector and recreational activities.
- Hiked prices of commodities and more so that of fish.
- Unemployment for the fishermen and fish vendors
- In accessibility to the source of drinking water by livestock and the local communities.
- Spread of diseases such as malaria
- Provision of habitats for animal’s e.g. different snake types and hippopotamus.

Efforts to control negative effects of the weed have involved various sectors, which have been active in trying to control its spread but with varying degree of successes. The local community tried the manual removal of the weed but the little success. Several NGO’S and other institutions laid vital role in trying to implement the various control method-physical and biological methods and educating the community.

The government’s role in enforcing legislations that concerns the weed is still uncertain. The weed has also been utilized sustainably by the community in various ways e.g. making furniture and for catching small fish for sale.
6.2 CONCLUSION
Aquatic weeds including water hyacinth have always existed but in recent decade their
effects/impacts have been magnified by man’s more intensives use of natural water bodies by
modifying them into canal and dams; polluting the water bodies with farm inputs and urban
waste waters, introducing aggressive plant species into new location among other means.
Eradication of the weed (water hyacinth) has proved almost impossible making even control
difficult.

As the serious negative implication of the presence of water hyacinth become more widely
recognized, the locals and institutions concerned should focus their attention more on the
positive effects of the weed; water hyacinth for instance, has the ability to remove toxic heavy
metals (copper, lead cadmium, chromium and manganese) from aqueous system during
production of large amount of plant biomass.

It is argued that the utilization of the weed may be the best way to control it as it helps to
minimize the economic input, it is environmentally sound and at the same time it provides some
of the much needed resources.

Turning this weed to productive use would look or seem desirable but only limited research has
so far been carried out and it’s long term consequences (i.e. 50-100 years to come) are unknown.
There may be some beneficial effects of water hyacinth through provision of suitable breeding
ground for fish and use of this weed for making handicrafts, furniture, papers, or used as
fertilizers and as mulch, but with heavy infestation these benefits are surpassed by the negative
effects. For this reason, the following recommendations may help tp accentuate the control
measures in place.
6.3 RECOMMENDATIONS

Community sensitization and participation programmes should be initiated and strengthened. The study reveals that most local residents do not know or appreciate the role of the government and thus the lack the urge to participate in it anyway:

- The major and the main recommendation is to provide disposal sites along the shores of lake Victoria; community will be paid according to dry water hyacinth they will collect and bring for weighing.

- The government should come up with efficient and effective policies and legislations to control fishing so as to avoid over fishing.

- There is need for constant monitoring of water hyacinth to aid in its control

- The fact that most of the effluent to the lake takes place in the gulf (231 m$^3$-1) and the only outlet being in the extreme opposite of the gulf, this would create a pressure along the channel through which the outflow occurs and there should be a near permanent flow from the gulf to the main lake. Determination of water budgets into and out of the gulf should be incorporated into some future study. This could help generate information on the occasional flooding in the Gulf

Recommendations to the communities

The locals should actively and genuinely participate in efforts to control the spread of weed, for instance through:

- Avoid transportation of the weed from one point to another.

- Engage in other income earning activities other than fishing which is greatly hampered by water hyacinth.
6.4 AREAS FOR FUTHER RESEARCH

- It seems that the problem of macrophyte encroachment in Lake Victoria is greatly enhanced by nutrient enrichment (Muli 1996). In controlling the problem, there is a need for a study in nutrient fluxes into Winam Gulf and the lake as a whole.

- There is also a need to study the effects of dumping huge amounts of organic matter on the lake's benthic biota; even though this study indicates that the breakdown of the organic matter does not take a very long time.

- More distributed current meter deployment in the whole gulf could be necessary to get longer time-series measurements. This could give better-established relations between wind and current such as the response time of the lake to the wind and dynamics of circulation in the Gulf. A better understanding of water exchange between the gulf and the main lake could be an interesting aspect that could be incorporated into the study. This could have a practical aspect in understanding the occasional flooding in the gulf.

- There is also a need to map the gulf's topography and an in-depth understanding of the movement of currents and the influence these have on sedimentation on a longer time scale.
REFERENCES


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