Research report

EFFECTIVENESS AND SUSTAINABILITY OF AQUATIC INVASIVE PLANTS MANAGEMENT IN LAKE CYOHOHA NORTH

PREPARED BY: Bernard NDAYISABA

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Executive summary

Rwanda's freshwater is threatened by invasive species of plants and animals. As consequences, aquatic invasive species displace other species, disrupt ecosystems, and harm recreational activities such as fishing and boating. This result to threats like food insecurity, water scarcity, diseases like malaria and bilharzia among others. This study aims to determine the effectiveness and sustainability of aquatic invasive plants management in the Lake Cyohoha North as well as its impact on the riparian community. Household surveys, field observation and interviews are among methods used to collect data. The results indicated that ecosystem services of the Lake such as water for their livestock, cooking, drinking, washing and irrigating their crop farms were compromised. Again fish production in the lake have been compromised which in turn affect community livelihoods. This research indicated that the effective management of aquatic invasive plants is to remove and use them in fertilizer production as it contributed to community livelihoods through direct employment, but also improvement of fishery production and access to water used in their daily activities.

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Chapter 1. Introduction

1.1. Background of the study

Human well-being and development depend on healthy ecosystems that provide not only fertile soil, clean water and food but also protection of our climate and adaption to climate change(GIZ, 2018). Climate change has been recognized to further assist the spread of invasive plants(Willis et al., 2010). Aquatic plants are seen to have a higher prospect to become invasive in new environments in comparison to terrestrial ones (Andreu & Vilà, 2010). Plant invasions can cause ecosystem degradation, human health problems, and direct economic losses through alternative services and management costs (Mccormick & Contreras, 2009; Hill, 2003). Globally there is a huge number of invasive species of which over 13000 are naturalized vascular plants species (Van Kleunen et al., 2015).

Invasive species can have many known and unknown potential impacts on community structure and ecosystem function. Although some invasive species have little or no detectable effects, many of them are harmful to the environment and human livelihoods (Havel et al., 2015). Over 12000 invasive species including plants and animals have been found in Europe only, and 15% of them have negative impacts (Vilà et al., 2010). More than 120,000 non-native species of plants, animals and microbes have invaded United States, United Kingdom, Australia, South Africa, India, and Brazil, and many have disturbed agriculture and forestry and negatively impacted ecological integrity as well (Pimentel et al., 2001).

Since the late 1800s, one of the largest threats to socioeconomic development throughout Africa have been the invasion of dams, rivers and lakes by aquatic invasive plants; they have affected transport, reduced fish production, impeded water access by local communities for different uses and are home to disease-causing agents (Cilliers et al., 2003;Darius O.et al., 2016).Invasive plants of natural ecosystems can reduce the abundance and the diversity of native flora and fauna, and alter ecosystem processes(Reid et al., 2009). These species were found to affect the ecosystem services such as provision services, regulating services, cultural services, and supporting services (Charles & Dukes, 2007;Pejchar & Mooney, 2009). It was revealed that invasive plants threaten freshwater ecosystems that are essential for human wellbeing(Walsh et al., 2016).

The most affected areas are six life-supporting sectors: food, water, ecosystem service, health, human habitat and infrastructure (MFAN, 2018) leading to impacted community livelihoods. Economy and livelihoods especially in developing countries rely on natural ecosystem and ecosystem services (eftec, 2005; Landreth & Saito, 2014). Rwanda possess hydrological network made of 101 lakes covering 149,487 ha, 860 marshlands with a total surface area of 278,536 ha and 861 rivers with a total length of 6,462 km (REMA, 2011) which provide a range of services; however natural ecosystems such as lakes are degraded due to anthropogenic activities and invasion by aquatic weeds (Valentine et al., 2018).

Bugesera district, within which Lake Cyohoha North is located, is the mostly impacted region by the rainfall fluctuation and drought. Recently Lake Cyohoha North was nearly drying due to different factors including drought and conversion of the surrounding feeder wetlands into farming(REMA, 2017). The high population density in the region coupled with increasing demand for cultivable land, the vegetation around the lake have been cleared which leads to severe erosion and siltation of the lake. The water quality has been affected due to eutrophication leading to poor ecosystem services of the lake which affected negatively the livelihoods of local community(REMA, 2019). Increasing of sedimentation and the presence of invasive plants species like *Ceratophyllum demersum*, *Potamogeton crispus*, *Nymphaea nouchalii*, etc were found to reduce the aquatic ecosystem capacity of the lake(Havel et al., 2015).

In order to improve the livelihoods of local communities living near degraded ecosystems, increase their resilience to negative impacts of climate change, protecting and conserving its natural resources; the government of Rwanda through Rwanda Environment Management Authority (REMA) has used an ecosystem-based adaptation (EbA) approach(REMA, 2017, 2019). This approach brings into play the use of natural resources by the community to adapt to climate change impacts, poverty reduction and improvement of livelihoods while mitigating the climate change impacts (Munang et al., 2013). It tackles on creating fundamental relations between climate change, biodiversity and sustainable resource management, preserving and enhancing ecosystems, allow the community to better mitigate and adapt to climate change (Naumann S. et al., 2011). It is also a key principle to protect the ecosystems that provide the essential 'life support systems' (ecosystem services) that we all depend on (Munang et al., 2013). The management of aquatic invasive plants in the Lake Cyohoha North aims at improving the livelihoods in the vicinity of the lake that were negatively affected by invasive aquatic plants (Rwanda Environment Management Authority [REMA], 2017).

1.2.Problem statement

According to the Rwanda's Fourth National Report to the Convention on Biological Diversity, the status of most aquatic ecosystems in Rwanda has been deteriorated over the years because of land reclamation for agriculture and settlement. In developing countries, one of the integral part of rural livelihood strategies and household resilience is ecosystem services (Mainka, Mcneely, & Jackson, 2008; Reynods et al., 2020). Governments progresses in addressing key sustainability goals such as poverty alleviation and food security is severely hindered by depletion of ecosystem services by invasive plant species(United Nations, 2015). Rwanda's freshwater biodiversity also was threatened by accidental or purposeful introduction of alien invasive species of plants and animals(REMA, 2009). These aquatic invasive plants are threatening lakes and rivers in Rwanda especially in Lake Cyohoha North. As consequences, aquatic invasive plants displace other plant species, disrupt ecosystems, and harm recreational activities such as fishing and boating. This result to threats like to food insecurity, water scarcity, diseases like malaria and bilharzia. Therefore, management practices have to be taken to quantify impacts of invasive plants on

ecosystem services especially those that are essential to rural livelihoods. Currently, the growing recognition of the impacts of aquatic invasive plants to community livelihoods and ecological integrity of Lake Cyohoha North remain poorly documented and poorly understood. This research intends to explore effectiveness and sustainability of aquatic invasive plants. It also promotes ecosystem services of the Lake Cyohoha North to the surrounding local community.

1.3. Research objectives

1.3.1. General objective

The main objective of this study is to evaluate the effectiveness and sustainability of aquatic invasive plants management in the Lake Cyohoha North, community resilience to climate change and the ecological integrity of Lake Cyohoha North.

1.3.2. Specific objectives

To achieve the main objective, this study will be centered on the following specific objectives:

1. To identify the factors contributing to water table variability of Lake Cyohoha North.
2. To assess the impacts of aquatic invasive plants on ecosystem services of the Lake to local community.
3. To assess the use of aquatic invasive plants removed from the Lake by local community to improve their livelihoods.

1.3.3. Research questions

1. What are the factors contributing to water table variability of Lake Cyohoha North?
2. What are the impacts of aquatic invasive plants in Lake Cyohoha North?
3. What is the use of aquatic invasive plants management by local community?

1.4. Significance of the study

The knowledge of the relationship between aquatic invasive plants management, community livelihoods and ecological integrity of Lake Cyohoha North will be used in decision-making intervention measures to restore the Lake Cyohoha North ecosystem and improve the livelihoods and welfare of the riparian community. Particularly, this study is useful to different stakeholders including, planners, administrators and private institutions responsible for the management of Lake Cyohoha North, as the information from this study can assist in the management of aquatic invasive plants and improvement of ecosystem services of Lake Cyohoha North. Additionally, this study will serve as a further reference point by the academic institutions and other interested individuals for further relevant research or implementation of different interventions that are important to the community living in close vicinity to Lake Cyohoha North.

Chapter 2. Literature review

Lakes water levels are influenced by a variety of factors such as climatic parameters (temperature, precipitation and evaporation), hydrology and anthropogenic factors (Hofmann, Lorke, & Peeters, 2008). Lake ecosystems especially in the lake's littoral and aquatic-terrestrial interface processes are heavily controlled by the extent, frequency and duration of Lake water level fluctuations (Gao, Xie, & Zou, 2019). Warmer temperatures and increased sunshine have been found to amplify the evaporation rate as resulting on the decline of water level of the lake (Arkian et al., 2018). Lake water level is influenced by the climate change especially precipitation as it is reported in different lakes like Hongze Lake (Cai, Ke, & Shen, 2020) and Lake Kinneret (Cai et al., 2020). Water level changes disturb the aquatic ecosystem, it worsen habitat availability, complexity, and quality but also have negative impacts on the lake ecosystems and their services (Gownaris et al., 2018; Kolding & van Zwieten, 2012;Gordon et al., 2003). Shallow lakes have been found to be vulnerable to eutrophication problems; eutrophication and cyanobacterial blooms may be amplified by water level fluctuations (Djihouessi et al., 2020). Furthermore, lake water levels fluctuation results in internal nutrient enrichment, keystone species weakening, loss of biodiversity and increase of nuisance and invasive species (Zohary & Ostrovsky, 2011).

Globally, invasive species are well-known to be drivers of social-ecological change; they reduce the supply of natural resources for households, negatively affect human health and safety and reduce the cultural value of landscapes which can result in losses of income and increased vulnerability (Hussner et al., 2017; Palmer et al., 2014; Reuben et al., 2018). Invasive aquatic plants cause a decline in primary production, affect water physicochemical characteristics and hinder the availability of water that the community use for different purposes (Kurugundla et al., 2016). They can also impede the hydroelectric installations water intakes and irrigation outlets (Aloo et al., 2013). From the literature it seems that different authors worked on aquatic invasive plants elsewhere. According to (Mack & Smith, 2011) aquatic invasive plants act as breeding grounds for disease causing agents and increase diseases. Other authors including Stone, 2005; Patel, 2012; Gichuki et al., 2012; Schultz & Dibble, 2012; Thomaz et al., 2015 reported that water hyacinth is a threat to fisheries and economy due to the cost of their control and community that depends on lake ecosystem services.

Aquatic invasive plant species are recognized as today's serious problem worldwide. Therefore, to reduce their negative impacts on the ecosystem, economy and human livelihoods physical, biological and chemical control measures have to be taken into consideration(Greenfield, 2004; Hussner et al., 2017). For the physical method harvesting, cutting, rot ovation, weed raking, hand pulling, dredge and excavation are applied (Dersseh et al.,2019). This method has been found slow and labor intensive for large and dense infestations(Gibbons et al.,1999); it also influence water quality, survival of aquatic animals and plants, available nutrients and cause turbidity (James et al., 2002; Greenfield et al., 2004,2006). Biological control method involves the use of an organism termed biocontrol agent that reduce the vigour, reproductive capacity or density of the

target weed by suppressing its populations (Cuda et al., 2008), for example weevils (*Neochetina eichhorniae* and *Neochetina bruchi*) have been used to control water hyacinth(Center and Dray, 2010), some fish species like Grass carp (*Ctenopharyngodon idella*), the only fish species that consumes large amounts of vascular aquatic plant biomass have been long used as biological control agent for submerged invasive aquatic plants (Catarino et al., 1997; Pipalova, 2006). Chemical control method involves use of herbicides that are applied directly on the leaves of the targeted weeds; for example ammonia, sodium chloride, barium chloride, and sulfuric acid have been used in the United States to control water hyacinth (Dersseh et al., 2019). Products that have been licensed for control of aquatic invasive plants around the world are: 2,4-D, bispyribac-sodium, carfentrazone-ethyl, copper, dichlobenil, Diquat, Endothall, flumioxazin, Fluridone, Glyphosate, haloxyfop-R-methyl, imazapyr, imazamox, metsul- furon methyl, penoxsulam, terbutryn and triclopyr (Hussner et al., 2017). These herbicides when applied on plants, their leaves coil within 24h and start sinking in few weeks (Penfound and Minyard, 1947).

Despite the fact that the invasive species pose threats to human livelihoods especially where the local economic systems are closely tied to the harvest of natural resources and/or where subsistence agriculture through reduced the supply of ecosystem services which are important for humans (Pejchar & Mooney, 2009a; Aloo et al., 2013;Van Wilgen & Richardson, 2014; Keller, Masoodi, & Shackleton, 2018); their management can generate income, improve agriculture production and contribute to community livelihoods. For example in India, the study on response of water hyacinth as a source of Potassium in the production of potatoes indicated water hyacinth to be a low-cost source of organic fertilizer rich in Nitrogen, Phosphorus and Potassium proved to increase potatoes production (Alam, Srivastava, Anand, Sinha, & Mishra, 2017). In Nigeria, water hyacinth is used together with animal manure to increase the productivity. It has proved to increase groundnuts yield when mixed with poultry manure and cassava yield when mixed with cow dung (Oroka, 2015). The study done in Kenya in the Lake Victoria, findings revealed that *Crotalaria ochroleuca* vegetables give better yield when treated with water hyacinth organic fertilizer than when treated with industrial fertilizer. Therefore the government was advised to encourage the local community to participate in the water hyacinth management as it creates job and improve the ecological integrity of lake Victoria (Andika O. Darius; et al., 2016). In China, water hyacinth was found to have capability to replace portion of protein feeds and roughage, its dry matter is rich in nutrients and crude protein, it has been found to be a good source of fish feeds after degrading its lignin and cellulose. Even though water hyacinth has been found to have high nutrients content, it has to be treated and remove the moisture content to be fed to the ruminants with high quantity and then the growth performance (Weiping Su 1 et al., 2018). Furthermore, the water hyacinth has been found to be a good feedstock for biogas production when mixed with cow dung (Njogu, Kinyua, Muthoni, & Nemoto, 2015). Water hyacinth has been prepared and used as raw material for handcraft; it was found to be slit and weaved easily compared to papyrus and also to produce quality handcraft materials like hats, handbag and sandals preferred by users (Tsiry Fanilonirina Rakotoarisoa, 2017). Other aquatic invasive plants like *Nymphaea nouchalii*, *Potamogeton crispus* and *Ceratophyllum demersum* have been used as a medicine to treat various diseases like diarrhea,

constipation, dysentery etc (Abonyo & Howard, 2012), and livestock feeds(Nichols & Shaw, 1986). They are also used as source of fertilizer (Motlak & Yeaser, 2008).

Chapter 3. Methodology

3.1. Geographical location of the study area

Lake Cyohoha North (Figure 1) is in Southeastern part of Rwanda, Bugesera District at 2°14'8.16"Latitude and 30°6'11.16"Longitude with an average elevation of 1344m above the sea level. It is covering an area of 10.44 km of length and surrounded by four sectors: Mayange, Musenyi, Ngeruka and Mareba.

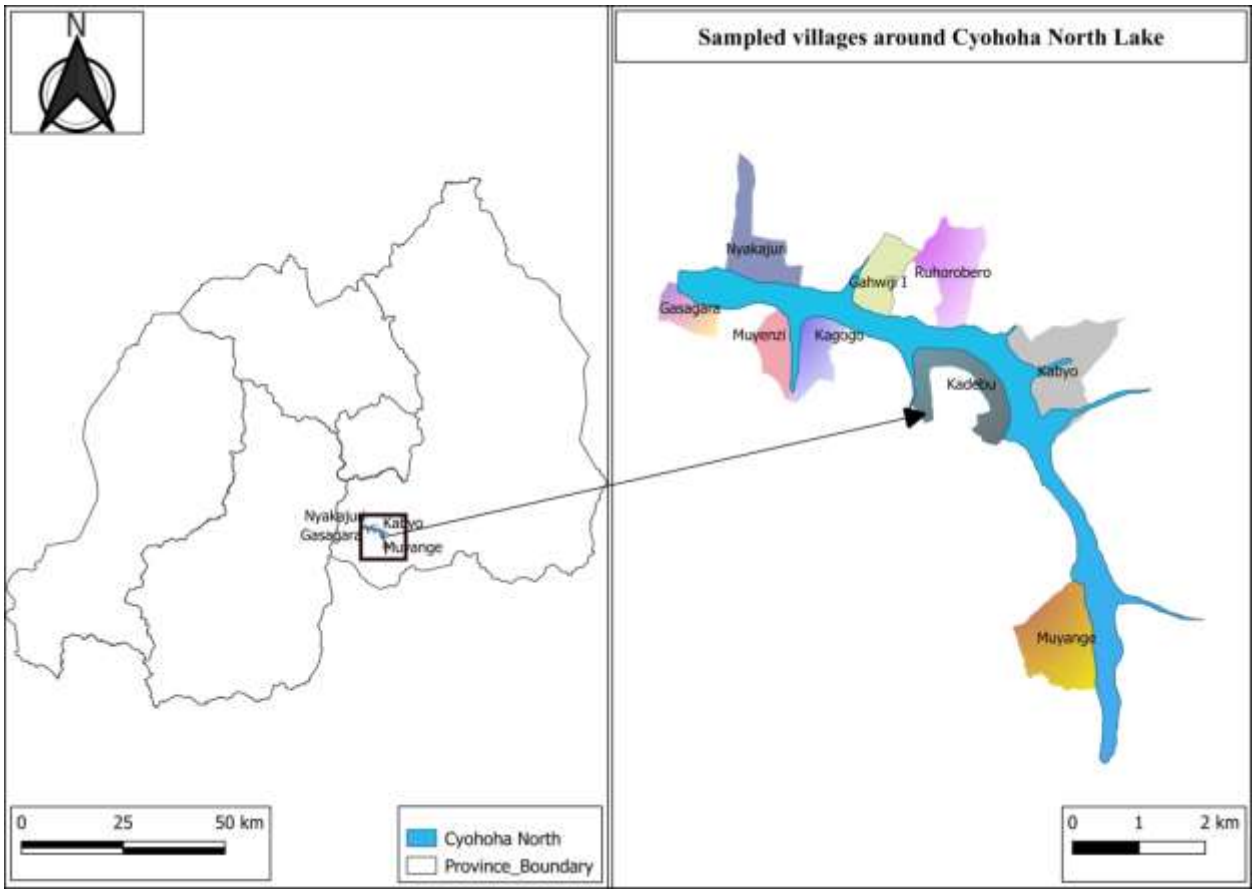


Figure 1: Map of Lake Cyohoha North showing the sampling sites

3.2. Research design

A descriptive cross-sectional study means qualitative and quantitative methods were employed. Qualitative information provided a more holistic picture on the contribution of aquatic invasive plants management to community livelihoods and ecological integrity of Lake Cyohoha North. Quantitative method was logically used when dealing with tabulation, presentation and analysis of data.

3.2.1. Study population

The study population was 11,244 people living in the four sectors around Lake Cyohoha North such as Mareba, Ngeruka, Mayange and Musenyi. Households members both males and females had equal chance to participate in the study.

3.2.2. Sample size

This research used random sampling where 9 villages out of 20 villages were selected randomly. The study was confined to Gasagara, Muyenzi, Kagogo villages of Mareba Sector; Kadebo and Muyange villages of Ngeruka Sector; Kabyo, Ruhorobero, and Gahwiji A villages of Mayange Sector and Nyakajuli village of Musenyi Sector. All these villages surround Lake Cyohoha North.

A sample size of people living around Lake Cyohoha North was calculated based on Yamane's formula below:

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

Where **n** is the sample size, **N** is the total number of the population living around Lake Cyohoha North and **e** is the precision level with standard error of ±5 % and confidence interval of 95%.

Based on the above formula, the sample size was:

n= [11,244/ (1+11,244(0.05)^2)]

n= [11,244/ (1+28.11)]

n=11,244/29.11

n=387 people.

3.2.3. Inclusive and exclusive criteria

The participants involved in this study were living in close vicinity of the Lake Cyohoha North who benefit from the lake's ecosystem services, affect the lake and are affected by the lake degradation. Both females and males, illiterate and educated people were eligible to participate in this study.

3.3. Data collection methods

The samples were collected through different methods such as field observation and photography, questionnaire during household survey, interview with local leaders at sector and cell level for primary data and documentary sources for secondary data.

3.3.1. Observation and photography

Observation is a process in which one or more persons look at what is happening in some real-life situation. By this method, the observation was made and photographic regarding the ecosystem services of the lake, water table variability, water use, and aquatic invasive plants usage was taken.

3.3.2. Interviews

Interviews were conducted using checklist of issues and questions to obtain the relevant required data on the contribution of aquatic invasive plants to community livelihoods. In-depth interview were organized with the 23 purposively selected key informants at local level such as leaders at sector and cell level at their offices to find out what they do, think or feeling about the contribution of aquatic invasive plants management to community livelihoods as well as the impact on the ecological integrity of Lake Cyohoha North.

3.3.3. Questionnaire based study.

During data collection, questionnaires composed of closed ended questions were designed in English and were translated in Kinyarwanda to facilitate the respondents. Participants were

selected randomly in their household and given questionnaires to provide their responses where 229 and 158 were male and female respectively. The number of male respondents was high because they are the heads of households and they respond on behalf of the family. Respondents were distributed in sectors as follows; 129 in Mareba, 105 in Ngeruka, 125 in Mayange and 28 in Musenyi and classified into two categories such as local community and community leaders (at village and cell level). The respondents were asked questions related to Lake Cyohoha North ecosystem services, how they are affected by its degradation, its restoration and the use of aquatic invasive plants removed from the lake then n responses were recorded for further analysis.

3.3.4. Secondary data collection

Secondary data were collected by consulting archive of weather parameters such as rainfall and temperature from Meteo-Rwanda and satellite images to check for climate change settings and land use land cover change. These data were used to witness the land use land cover change, contributing factors to Lake Cyohoha North degradation and its restoration.

3.4. Data processing and analysis

Data collected were cleaned and statistically analyzed using Microsoft Office Excel package and R statistical software; findings were presented in form of pi-charts, graphs and frequency tables for which recommendation and conclusions were based. The variables to be presented are those most central to the goals of the study. The contents of these tables are percentages, frequencies or some summary statistical measures which are analyzed using MS excel pivot table.

To produce maps that show land use land cover change and their relative surface area; satellite images were analyzed using visual image analysis technique, which was employed on different high-resolution images accessed through Google earth. The visual analysis technique involved first, geographic corrections (georeferencing) of the Google earth images so that they can be incorporated with other existing spatial data in ArcGIS software. Second, onscreen digitization has been applied to delineate water bodies boundaries in respective images and related statistics were computed through created attribute table.

3.5. Ethical issues

Individual's rights to privacy and confidentiality have been addressed by keeping anonymous all respondents. Respondents have not been asked to display their names. The consent of respondents was sought, in that before the interview or discussion. Before the conduct of any discussion or interview, the respondents were briefed on the purpose of the research and were asked to freely provide correct answers.

3.6. Demographic information

Socio-economic characteristics (Table 1, figure 2 and figure 3) are visualized to influence community in management of aquatic invasive plants. In this study, the socio-economic considered are gender, occupation and education level.

Table 1: Gender distribution of respondents

Sectors	Respondents				Total	%
	Males	%	Females	%		
Mareba	76	19.6	53	13.7	129	33.3
Ngeruka	62	16	43	11.1	105	27.1
Mayange	74	19.2	51	13.2	125	32.3
Musenyi	17	4.4	11	2.8	28	7.3
Total	**229**	**59.2**	**158**	**40.8**	**387**	**100**

Considering gender, the research showed that most of the respondents were males (Table 1). A big number of males in the study could be associated with the activities carried out in the lake like fishing. Natural resources management experiences, concerns and capability of people depend on gender and in turn influenced by gender relations (Masika & Joekes, 1997); women are preoccupied by domestic activities(Witt et al., 2010); hence less participation in this study.

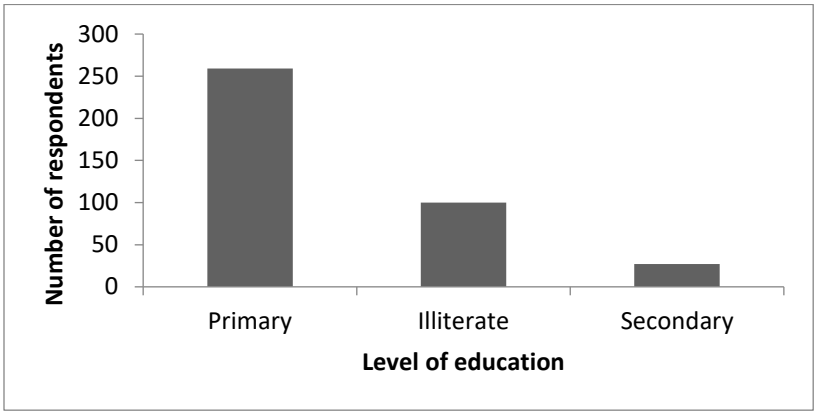


Figure 2: Level of education of respondents

The majority of respondents from the community around Lake Cyohoha North have primary education (67.1%) and others didn't attend the school (25.9%) (Figure 2) meaning that they are mainly occupied by on farm activities and have minimal alternative ways to make living. This also is shown below where many of them are farmers and fishermen while tiny number is handcrafters (Figure 3).

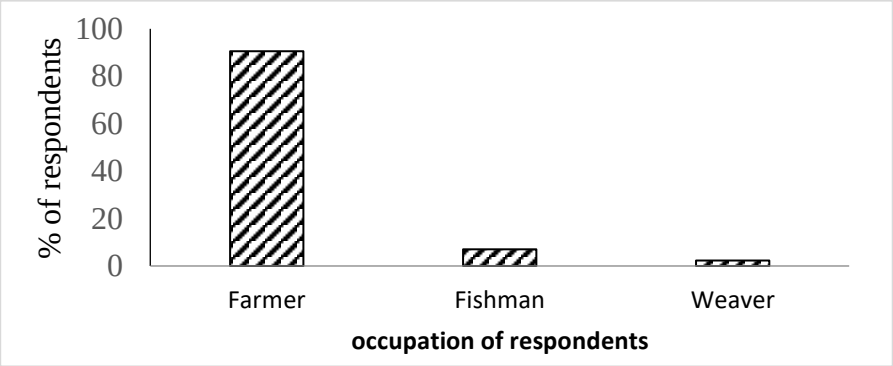


Figure 3: Occupation of respondents

Chapter4. Results

In this chapter, research findings on factors contributing to Lake water table variability, affected ecosystem services, control measures and use of aquatic invasive plants.

4.1. Factors contributing to water table variability in the lake Cyohoha North

Water table variability can be influenced by many factors; some of them are of natural origin and others are human made. Human made factors involve transformation of wetland into agricultural land which reduce the capacity of water retention of wetland and deforestation that lead to erosion. ARCGIS 10.4 has been used to detect the landscape change over time and examine the level of different factors.

4.1.1. Land use land cover change

The landscape of Bugesera district where Lake Cyohoha North is located used to be naturally intact. Human population has been increased which has lead to conversion of land for food production, forest clearing for settlement and other infrastructures.

Field observation and satellite images indicate a great change in land use land cover in the Lake Cyohoha North catchment. The region recognized an increased agricultural surface and settlement surface area while wetlands, grassland and forest have been reduced (Figure 4). This can read to high erosion and the soil with fertilizers get into the lake, also water retention capacity of wetland that supply water to the lake have been reduced due to drainage hence the decreased lake water level and siltation.

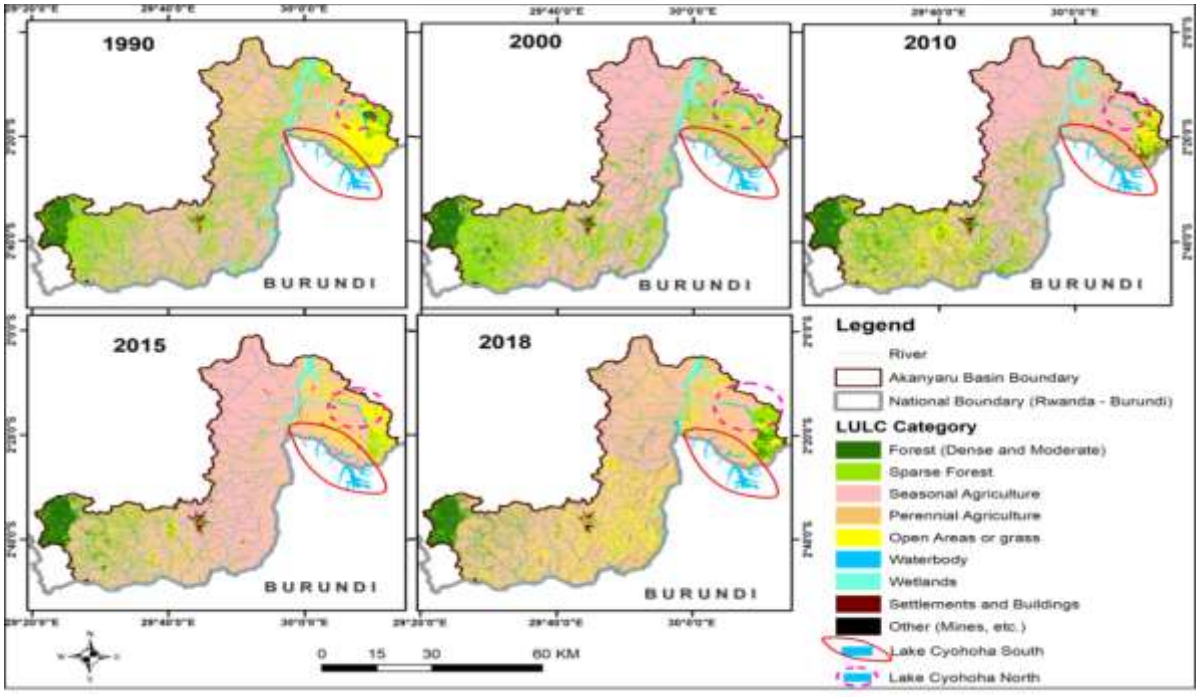


Figure 4: Land use Land Cover Change in the Lake Cyohoha North catchment.

Table 2: Surface area of land use land cover change

	1990		2000		2010		2015		2018	

LULC	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
Forest (Dense and Moderate	12124.6	**3.6**	21372.7	**6.3**	25916.4	**7.6**	16382.2	**4.8**	23246.5	**6.8**
Sparse Forest	99386.9	**29.2**	89724.1	**26.5**	66940.4	**19.7**	36708.6	**10.8**	29098.1	**8.5**
Seasonal Agriculture	174805.3	**51.3**	193851.4	**57.2**	199835.2	**58.7**	240924.6	**70.8**	195298.1	**57.3**
Perennial Agriculture	1944.6	**0.6**	715.4	**0.2**	2083.5	**0.6**	1422.6	**0.4**	20548.6	**6.0**
Open Area or Grassland	31825.1	**9.3**	16387.9	**4.8**	27784.4	**8.2**	32686.3	**9.6**	61682.2	**18.1**
Water body	2857.2	**0.8**	2401.9	**0.7**	1958.9	**0.6**	2420.1	**0.7**	3648.8	**1.1**
Wetlands	16522.6	**4.9**	13507.3	**4.0**	13467.5	**4.0**	6708.0	**2.0**	6149.5	**1.8**
Settlements and Buildings	794.4	**0.2**	950.4	**0.3**	2132.8	**0.6**	2999.8	**0.9**	1431.9	**0.4**
Other / No Data	224.7	**0.1**	224.7	**0.1**	369.2	**0.1**	234.8	**0.1**	1.8	**0.0**

4.2.2. Climate change (prolonged drought and heavy rainfall)

Temperature and rainfall are major factors that greatly influence climate of a region. Bugesera region recognize a change in temperature and rainfall since 1990s (Figure 5&6). Based on meteorological data (rainfall and temperature) and reply from respondents (82.9%), the area recognized periods of prolonged drought and serous heavy rain and this dried the lake in 2003 and filled up in 2006 as respondents replied.

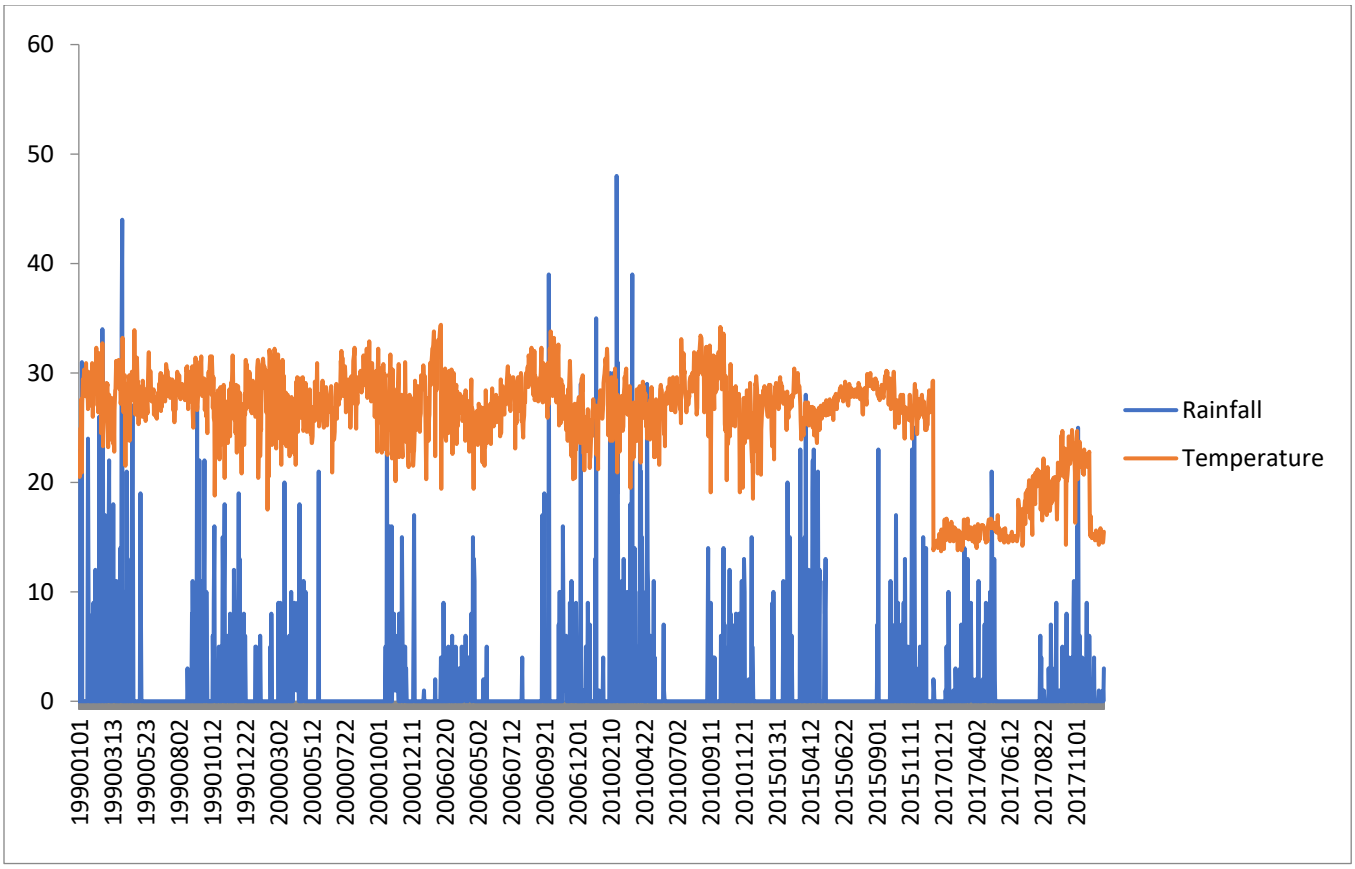


Figure 5: Temperature and rainfall in the region where Lake Cyohoha North is located

4.3. Impacts of aquatic invasive plants on the ecosystem services of the Lake

4.3.1. Aquatic invasive plants abundance based on respondents perceptions

Lake Cyohoha North is invaded by different aquatic invasive plant species such as hornwort (*Ceratophyllum Demersum*) water lily (*Nymphaea Nouchalii*) and Curlyleaf pondweed (*Potamogeton Crispus).* Based on community perceptions, the abundance of aquatic invasive plants is as follow: hornwort (*Ceratophyllum Demersum*) 55%; water lily (*Nymphaea Nouchalii*) 38% and Curlyleaf pondweed (*Potamogeton Crispus)* 8%. According to the field observation, hornwort (*Ceratophyllum Demersum*) is aggressively invading the lake.

4.3.2. Impacts of aquatic invasive plants on ecosystem services of Lake Cyohoha North

The presence of aquatic invasive plant species has negative impact to ecological health of the lake, its ecosystem services, human health and economy. From the responses of participants, 52.9% indicated that aquatic invasive plant species reduce water quality and they fetch unclean water, 26.5% replied that there is a decrease fish production capacity of the lake while 14.7% said that they cause water scarcity and 5.9% reported that it is difficult to fetch water (Figure 6).

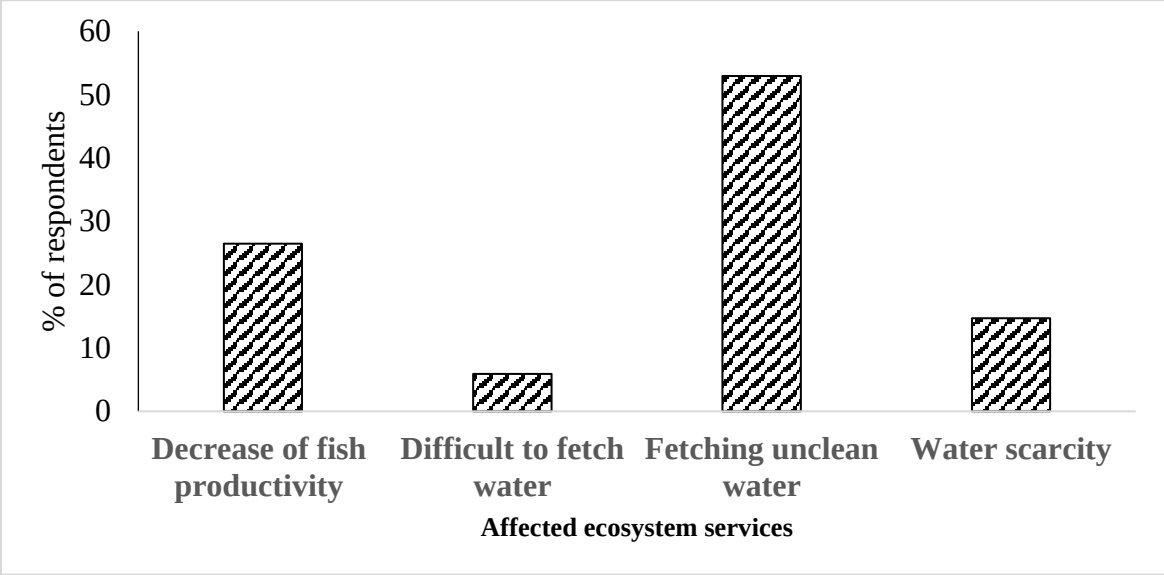


Figure 6: Impact of aquatic invasive plants on the Lake and its ecosystem services

4.3.3. Ecosystem services of Lake Cyohoha North

4.3.3.1. Uses of Lake Cyohoha North

Prior to household survey participants indicated that the lake is important to them where 55.5% said that they use it to get water for different domestic uses; water for irrigation 20.2% and as transport root from one area to another 7.5% (Figure 7).

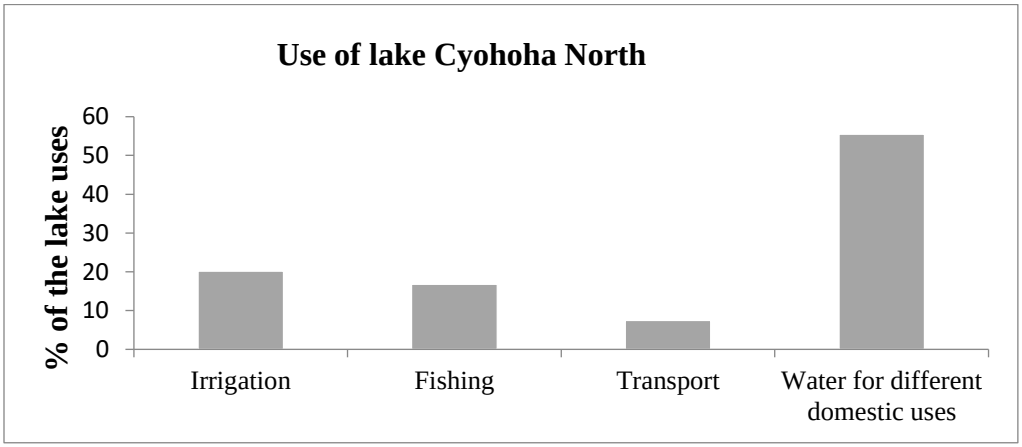


Figure 7: Use of Lake Cyohoha North by local community

4.3.3.2. Management of aquatic invasive plants

The government of Rwanda through REMA and other stakeholders started the management of aquatic invasive plants in the Lake Cyohoha North. In the Lake Cyohoha North, the management of aquatic invasive plant species is done by mechanical removal where they use boats to transport them to the lakeshore. This has increased lake water surface area from 345.5 hectares in 2014 to 588.5 hectares in 2018 as satellite images show.

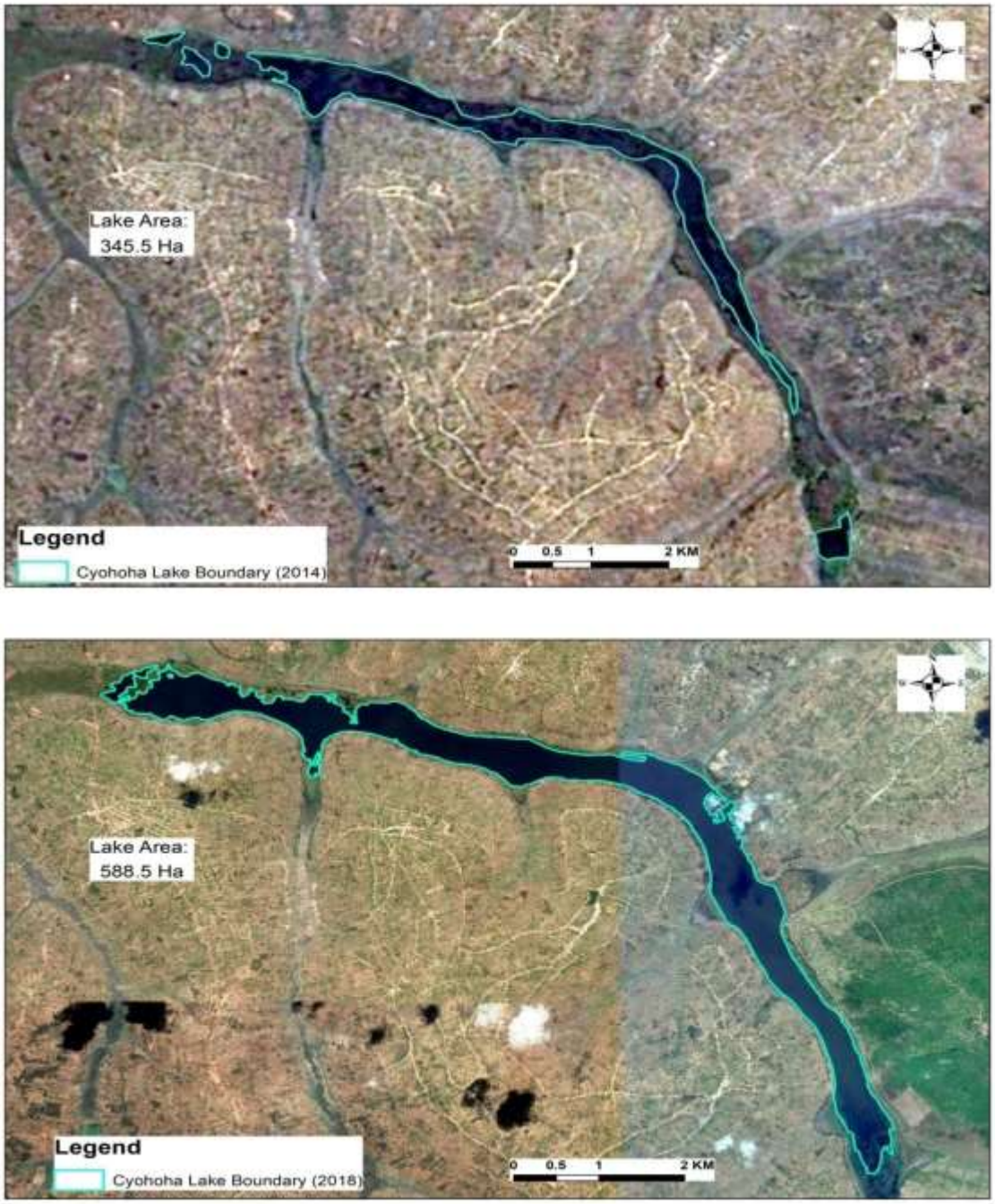
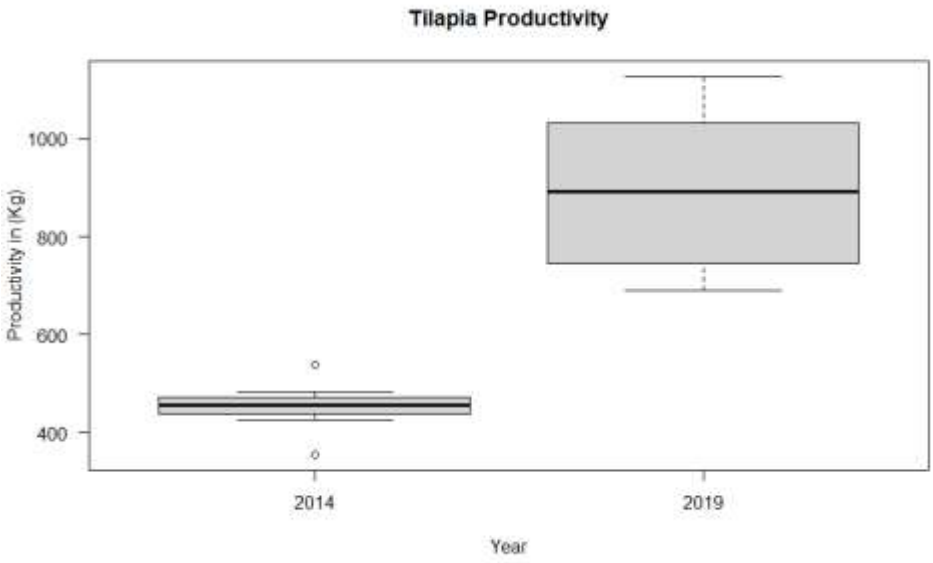


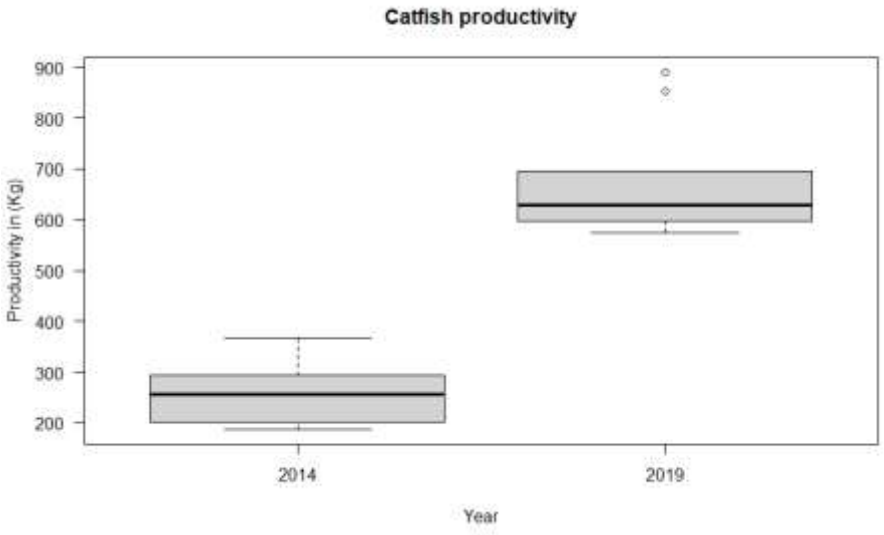
Figure 8&9: Surface area before and after management of aquatic invasive plants

The management of aquatic invasive plants resulted in fish production improvement. Lake Cyohoha North has different fish species dominated by three species such as; Tilapia African catfish and Protopterus. The results from this study showed that fish production before and after management of aquatic invasive plants are statistically significant as the P-value is less than 0.05(See below figures).



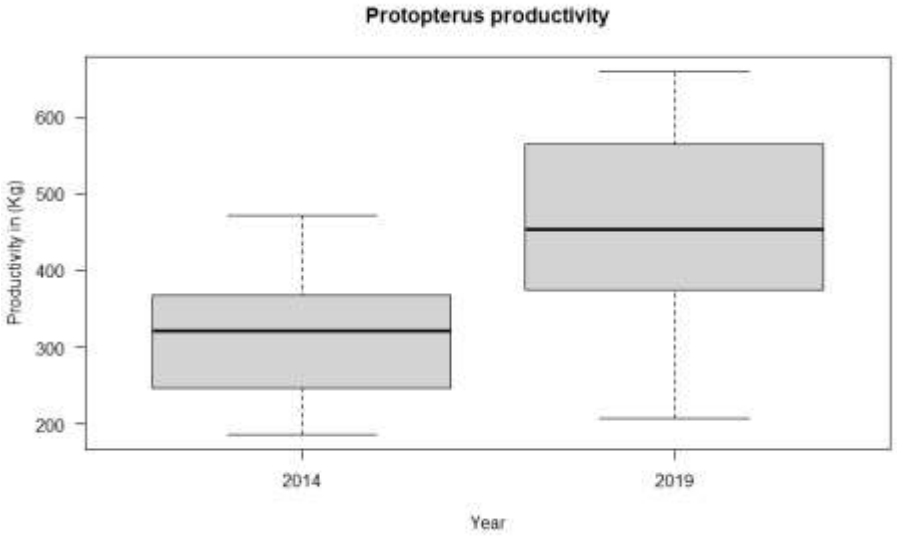
t = -9.6242, df = 8, p-value = 1.129e-05

Figure 9: Tilapia production before (2014) and after (2014) removing aquatic invasive plants



t = -13.968, df = 8, p-value = 6.687e-07

Figure 10: Catfish production before (2014) and after (2019) removing aquatic invasive plants



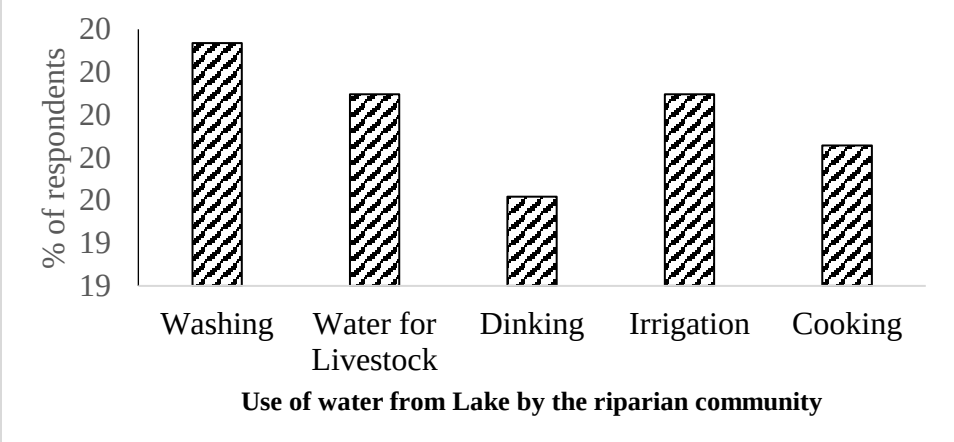
t = -4.8522, df = 8, p-value = 0.001268

Figure 11: Protopterus production before (2014) and after (2019) removing aquatic invasive plants

The management of the aquatic invasive plants also leads to the improved ecosystem services of the lake to the surrounding community; their removal increased fishery production, water availability for different uses where an average of 506.72 cube meters are used in household activities and 1896 cube meters are used in agriculture per year based of reply from respondents. The improvement of ecosystem services is also seen in the cost of hiring land. The value of the nearby land to the lake is 240,000 rwf per year while that for the land that is far from the lake is 150,000 rwf per year replied by 83.6% of respondents.

4.3.3.2. Uses of water from Lake Cyohoha North by the riparian community

People depend on water from the lake for their daily life activities. The results showed that water from the lake are used for drinking (19.6%), cooking (19.9%), irrigation (20.1%), washing and cleaning (20.3%) and water for livestock (20.1%).



Use of water from Lake by the riparian community

Figure 12: Use of water from Lake Cyohoha North by local community.

4.3.4. Methods used to protect Lake Cyohoha North

The management of aquatic invasive plant species and conservation of Lake Cyohoha North is efficient and sustainable as it is seen through this study where the respondents showed that they have a certain knowledge to protect the lake integrity such as planting trees in the buffer zone, avoiding cultivation in less than fifty meters, removal of invasive plant species, fight against erosion and protection of the buffer zone trees (Figure 12).

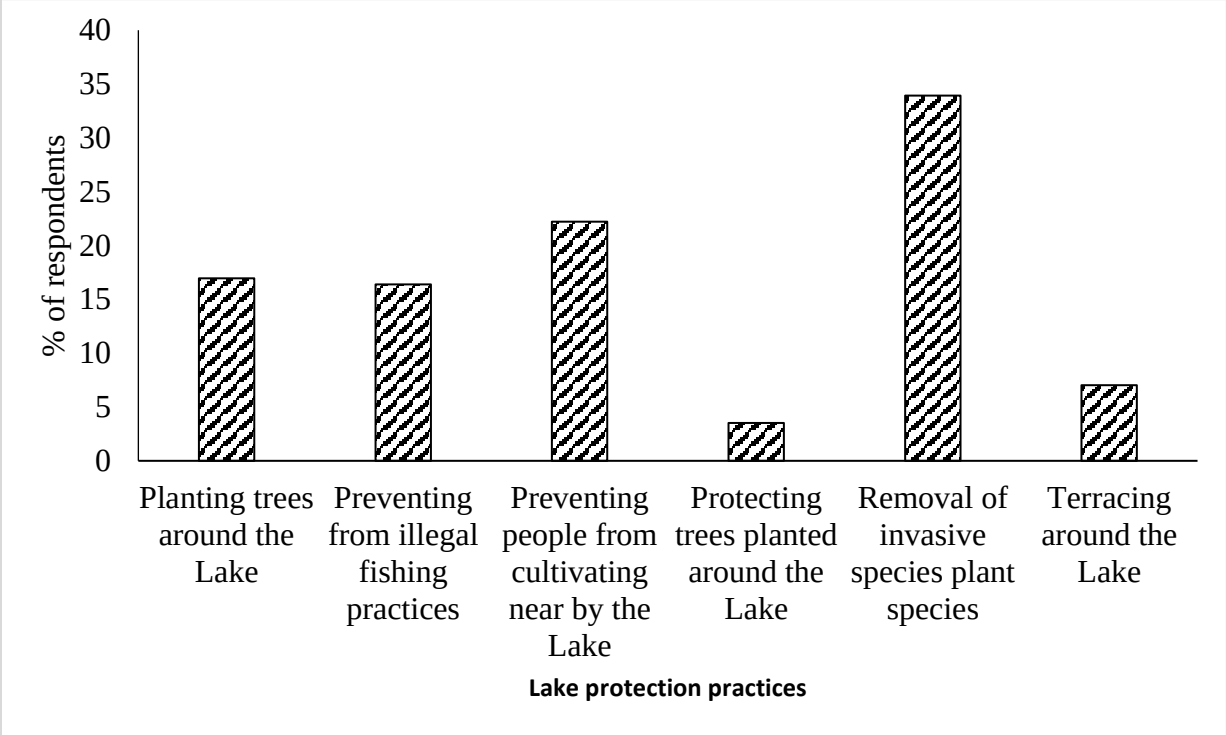


Figure 13: Methods used to protect Lake Cyohoha North

4.4. Use of aquatic invasive plants removed from Lake Cyohoha North

4.4.1. Fertilizer production and livestock fodder from aquatic invasive plants

Management of aquatic invasive plants contributes to community livelihoods and welfare when removed from the lake. Community in the lake catchment use aquatic invasive plants removed from the lake as fertilizer and proved that this fertilizer boosts their agricultural production like tomatoes, beans, maze and onions as follow; 33%, 55%, 25% and 12.5% respectively as the majority replied (73%).Again, their management has provided job opportunity to 7.1% of local community around the lake and 11.9% use some of the plants fodder for livestock as said by respondents. In addition, the fertilizer is free of charge when respondents were asked how much they could pay (willing-to-pay) if the fertilizer is to be sold; they said they could pay 300 rwf per basket.

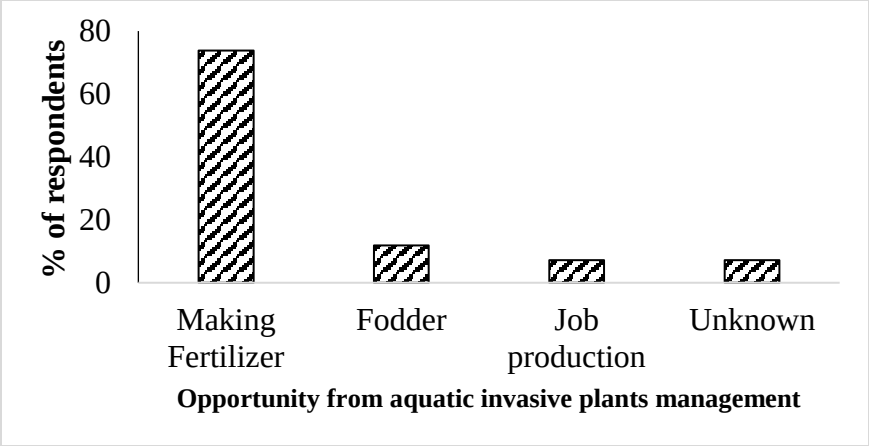


Figure 14: Use of aquatic invasive plants

4.4.2. Use of aquatic invasive plants for handcraft production

Aquatic invasive plants are used in handcrafting when removed from the lake like chair, basket, sleeping mat, wicker plates and woven grass mat. Community make profits from these handcrafts as shown in the table below and this improve their livelihood.

Table 3: Monthly production of handcrafts from aquatic invasive plants

Item	Cost	Average monthly production per person
Chair	2000frw to 5000frw	14
Sleeping mat	500frw to 3000frw	39
Wicker plate	200fwr to 300frw	7
Woven grass mat	15000frw	2
Basket	2000frw to 3000frw	1

Chapter 5. Discussion

According to the national population census, Bugesera district was recognized to have an increase in population density from 181 inhabitants/ km^2 in 1980 to 282 inhabitants/ km^2 in 2012 (Hategekimana and Semana, 2013). Human population growth leads to the high land occupancy and conversion of natural lands to agriculture and other uses, hence the land use and land cover changes (Kanianska, 2016). The results of this study proved that people used Murago wetland and the lake proximity as a farm land to improve their agricultural production (Table 2 and figure 4) but this prime the drainage of the wetland. Furthermore, Walters & Shrubsole(2003) and Blann et al., (2009) stated that the increase of agricultural production alters the wetland functions and values such as maintenance of ground water levels, water quality improvement, wildlife habitat and erosion control among others. Choiński et al., 2012 in their research conducted in Poland on eleven lakes supported this by arguing that agricultural drainage decrease significantly Lake water level and may lead to its disappearance within a short time.

Similarly, the results of this study confirmed the land use land cover change (Figure 4). Ptak et al., 2013 in a study done on Lake Jelenino revealed that land use land cover change through agricultural activities around the lake affect the livelihood of community living near the lake where they are required to shift from fishing and engage in other activities.

The results also confirmed the change in climatic conditions such as temperature and rainfall (Figure 5). Forster et al., (2007) in their research evidenced that land cover change including clearing of forests and natural grassland for crops, settlement or grazing, substitution of crops and grasses by forests influence the regional climate and affect the surface albedo and radiative forcing. Pitman, (2003) showed that this lead to partitioning of available energy between sensible and latent heat, boundary layer temperature, moisture profile and depth, and the partitioning of rainfall between evaporation and runoff. The results from this research showed that climatic variability and change lead to Lake water level change as a result of prolonged drought and heavy rain. Starks et al., 2014; Van Der Kamp, Keir, & Evans 2008 proved that drought and precipitation lead to increase and decrease of water level in the lake in their research.

In this research, it is demonstrated that ecosystem services of Lake Cyohoha North to the surrounding community have been highly affected. The ecosystem services that are highly affected are water that are used by community for different purposes and fish production. The reasons behind were prolonged drought, invasion of the lake by aquatic invasive plant species and heavy rainfall on bear ground that take soil with fertilizers to the lake. Kafumbata et al., 2014 found that lake water level and basin rainfall change with ecosystem and livelihoods benefits. This have seen to be a challenge to the community by reducing the quality and quantity of ecosystem services and goods which in turn reduce economic opportunity, hence food insecurity(Pederson et al., 2006;Kambewa, 2005). Again Grizzetti et al., 2019 said that one of fundamental service that nature offers to humans is fresh water and that groundwater, rivers and lakes could be sources of clean water for drinking purposes and domestic uses, and for economic activities, such as industry, energy production, irrigation and livestock.

Even though community around Cyohoha North Lake have been greatly affected by the invasion of the lake by aquatic invasive plant species, they turned them into profit where they use plants that are removed from the lake as a source of organic fertilizer, folder for livestock and they earn money through removing them(figure 13). Different studies revealed that these aquatic invasive species could turn from being problematic to a source of income and empower community economically by boosting agricultural production while maintaining the lake ecosystem services(Darius O. et al., 2016; Jafari, 2010; Motlak & Yeaser, 2008; Vidya & Girish, 2014).

The surrounding community of Lake Cyohoha North uses some of the invasive aquatic plants to produce different handcrafts such as chairs, sleeping mats, wicker plates, woven grass mats and baskets. They make money from these handcrafts and boost household incomes. Rakotoarisoa et al., 2016 examined the use of water hyacinth as raw material for handcrafts in poor and remote area near the Lake Alaotra. They found that water hyacinth which was a serious problem in lakes and rivers of Madagascar tuned into profit; it became potential to increase local household incomes, open up new markets, and reduce the pressure on the Alaotra wetland biodiversity. Again, Báez-Lizarazo et al., 2017 conducted a research in the north coast of the state of Rio Grande do Sul in southern Brazil and found that communities use invasive plants in the production of handcrafts to complement family incomes.

Chapter 6. Conclusion and recommendations

6.1. Conclusion

Bugesera is a region that possesses numerous water resources yet it suffers from meteorological and hydrological drought which affect the livelihoods of community (Hategekimana et al., 2013). This research revealed that the main threat to this region especially around Lake Cyohoha North and its catchment is land use land cover change, climate change and invasion by aquatic invasive plant species. This affects ecosystem services of the lake and leads to its disappearance. Again, this research revealed that the management of aquatic invasive plants in Lake Cyohoha North is done by mechanical removal; this has increased the surface area of the lake and the availability of water to local community. In addition, the management of aquatic invasive plants led to improved fishery production based on record of fishing cooperative. Fertilizer from aquatic invasive plants has shown potential to boost agricultural production. All these contribute to community livelihoods and welfare as the lake became healthy and provide its ecosystem service to the riparian community.

The management of aquatic invasive plants can be effective and sustainable as long as the riparian community continue to remove these grasses and use as fertilizer and in their handcraft

6.2. Recommendations

The area where Lake Cyohoha North is located has been affected by prolonged drought and heavy rain. According to the results of this study, the main causes were deforestation, wetland transformation into agricultural land and erosion that put nutrients into the lake. Therefore the government should encourage reforestation, measures to fight against erosion and agro forestry in the area.

The cultivation of the wetland and its branches reduces capacity of the wetland to retain water which in turn affects Lake Cyohoha North because during dry season water in the lake flow back to the wetland. An in-depth study on effect of cultivation of Akanyaru and other marshlands connected to Murago wetland has to be conducted so that it is done wisely and in sustainable way that do not obstruct ecological functionalities of the wetland.

Aquatic invasive plants are problematic; they impaired ecosystem services of the lake to the surrounding community. Aquatic invasive plant species can also be a source of opportunity especially when removed they are transformed into organic fertilizer. The government should support the regular removal of aquatic invasive plants and their transformation into fertilizer.

Again, upon to the removal of aquatic invasive plants, fishery in the Lake Cyohoha North has been increased. The government should promote fishery as it is a source of income to local community.

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Appendices

Lake Cyohoha North after removal of aquatic invasive plants species and people are benefiting from its ecosystem services like fetching water for different domestic uses, watering livestock and pumping water for irrigation.