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Effects of cage fish farming on water and sediment quality in Lake Kivu, Rwanda

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A dissertation submitted in partial fulfillment of the requirements for the Degree of Master of Science (MSc) in Environmental Chemistry.

Kigali, July 2024

DECLARATION AND COPYRIGHT

I, **Aboubakar DUKUNDIMANA** hereby declare that this master dissertation entitled *"Effects of cage fish farming on water and sediment quality in Lake Kivu, Rwanda*" is my own original work. It is submitted at the University of Rwanda for partial fulfilment for the award of the Degree of master's in environmental chemistry of the University of Rwanda. This dissertation has never been submitted and will not be submitted elsewhere for any other award of a degree or academic certificate.

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Supervisors:

We supervisors of this master dissertation, confirm for its originality and that it has been submitted for examination with our approval.

Dr. Jean Felix MUKERABIGWI Date: / / 2024 Signature:

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This is to certify that the dissertation report titled “Effects of cage fish farming on water and sediment quality in Lake Kivu, Rwanda” is the genuine work of Aboubakar DUKUNDIMANA registered to 221026743 in partial fulfillment of the requirement for the award of a master’s degree in environmental chemistry from College of Science and Technology at University of Rwanda.

Supervisors: Dr. Jean Felix MUKERABIGWI

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Dr. Marcelin RUTEGWA

Date: ………………. 2024

DEDICATION

I dedicate this dissertation.

To Mom, who took me to school!

To my close friend, who supported me a lot during my master’s studies!

To the people who have worked hard to help us complete this project

ACKNOWLEDGEMENT

I would like to express my appreciation to my supervisors, Dr. Jean Felix MUKERABIGWI, Dr. Jean Bernard NDAYAMBAJE and Dr. Marcelin RUTEGWA for giving me the necessary support and encouragement. Without them this research would not been accomplished. I am indebted to each person with whom I have collaborated on this project. Each member of my dissertation committee has shared with me a wonderful scientific research experience and life in general, as well as giving me a lot of advice for both my personal and professional life. I also thank the Chemistry Department for every support they have given to me. I would not have been able to complete this project without the financial assistance from SPORT-EA project and technical support of Ms. Janvière TUYISENGE.

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Last, I thank my family for being patient with me throughout the period of the program. Above all praise is to Allah for protecting my life throughout the period of the program.

ABSTRACT

Human activities in the lakes and around the lake water such as settlements, ports, agriculture, households, industry, and cage fish farming are increased due to population growth and good climate around the lakes. This caused an increase of water and sediment pollution and effect aquatic organisms. The aim of this research conducted on lake Kivu from October to December 2022 was to investigate the effect of cage fish farming on the environment. Water and sediment samples were collected in three sites, namely one site with cage farming at Kigufi and two control sites hot spring and, Nyamwenda. Variables measured in water are depth, nitrate-nitrogen, ammonium-nitrogen, phosphate-phosphorus, total suspended solids (TSS), secchi disk, and chlorophyll a as indicators of water quality. Variable measured in sediment was organic matter content as an indicator to show the quality of sediment. One way ANOVA was used to test statistical significance between caged area and control site. $P > 0.05$ indicates statistical insignificance, whereas $P < 0.05$ indicates significance. The results from analysis showed that there were variations in Nitrate-nitrogen, phosphate-phosphorus, chlorophyll a analysis at all profile level but were not significantly different between the inside the cage and control site in October, November, and December (ANOVA, $P>0.05$) and were under the permissible limit according to World Health Organization (WHO) guideline. Secchi disk results showed statistical significantly all months (ANOVA, $P<0.05$ and range between 4 – 2 m but does not exceed permissible limit for all parameter tested. Total organic matter in October ranges from 5.89-7.72% and 5.1-7.57% in November, suggesting that Lake Kivu may not have been contaminated by organic matter. Total Organic Matter (TOM) levels did not differ significantly from those at the reference location ($p> 0.05$) in November and October. Sediment in the lake Kivu was sand has low organic matter due to greater pores that allow water for good oxidation. All of the analyzed parameters were within the recommended ranges and did not show any significant changes. In this research, we found that there is no environmental pollution caused by cage fish farming activities, therefore it can be allowed in Lake Kivu, Rwanda, with close monitoring of its impacts.

Keywords: Cage fish farming, Lake Kivu, Nutrient, waste, sediment, and Water quality.

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CHAPITER 1. INTRODUCTION

1.1. Background

Cage fish farming is a technique of growing fish in enclosed basket, bag, wooden or net that allow water exchange between the interior and outside of the cages (Figure 1). The reduction in fish capture in Rwanda and high demand of fish stimulated investment in cage fish farming since 2000 to fill the gap of fish production [1]. Cage aquaculture was expanded on African inland water and has capacity to diminish deficit of the fish in the area and provide additional advantages like employment and income. Nevertheless, if not appropriately guided and directed, cage aquaculture could no longer sustainable, causing space competition with other water users, natural corruption and economic losses to aquaculture. To maintain ecological balance of cage aquaculture, pisciculture utilize methods that lead the sustainability in cage aquaculture like improving feed rate in the cage [2]. Without monitoring of cages that show how to solve the problems that lead proper management concerning water quality, cage aquaculture may pose a risk of polluting the environment and cause economic crisis to aquaculture goals. Rwanda hosts 8% of cage aquaculture installations in the sub-Saharan Africa. In Rwanda, cage aquaculture is in Lake Kivu, Lake Muhazi, Lake Burera and Lake Ruhondo [2, 3].

Figure 2: Cage fish farming at Kigufi in Rubavu district (taken on 5th May 2023 at 10:30 Am).

The primary reason cage aquaculture has an unfavorable impact on the environment is that it requires a significant amount of fish feed and metabolic waste, both of which kill aquatic animals and increase competition for food among other species [4]. Large amounts of organic and inorganic waste are discharged into the environment because of the high input of fish feed and metabolic waste. High quantities of nitrogen (N) and phosphorus (P) in the organic wastes released by cage fish farming have the potential effect on water and sediments thereby causing to local eutrophication and changing the composition of benthic organic matter [5]. Other consequences of cage fish farming include introduction of non-native species and space competition among users and loss for ecosystem services that they would benefit due to high nutrients from fish feed and waste produced by fish. Cage culture was anthropogenic activity has negative environmental effect due to contributing to climate change results from the production of greenhouse gases (GHGs) such as carbon dioxide ($CO_{2)}$, methane ($CH_{4)}$, and nitrous oxide (N_2O), as the cage fish farming industry has expanded [4, 6].

1.2. Problem statement

Human technology increase result in the contamination of water bodies due to the production of toxic pollutants at concentrations above the limits set by World Health Organization (WHO) and Rwanda environmental management authority (REMA). Cage fish farming plays a very important role in degrading the water quality, sediment, and greenhouse gases emissions by releasing their waste in rivers, lakes, and oceans [7]. Different wastes are discharged from cage fish farming such as uneaten feed and metabolic waste which lead to contamination water bodies (Figure 2) [8]. The reduction of dissolved oxygen concentrations below a certain level due to decomposition of organic matter can cause increase in fish mortality rates [9]. The quality of water and sediment are greatly impacted by cage fish farming, which creates emissions of GHGs. Unconsumed fish meals and metabolic waste, for example, increase the amount of nutrients in the water and boost the amount of organic matter in the sediment, which both contribute to the generation of GHG emissions [4].

***Figure 3: Water quality contamination of cage fish farming** [1]*.

1.3. Hypothesis

Cage fish farming significantly affects water quality and increases organic matter in sediment.

1.4. Objectives research

1.4.1. General objective

To compare the physical and chemical characteristics of the Lake surface water, middle water, and bottom water at cage and non-cage fish farms in Lake Kivu.

1.4.2. Specific objectives

1. To evaluate physicochemical characteristics of surface water from cage farms and non-cage farms.
2. To assess physicochemical characteristics of middle water from cage farms and non-cage farms.
3. To determine the change in physicochemical characteristics of bottom water from cage farms and non-cage farms.
4. To assess physicochemical characteristics of sediment from cage farms and non-cage farms.

1.5. Significance of the study

This research is very important for examining the consequences of cage aquaculture practices on the water quality, and sediment in Lake Kivu. As part of the study, the physicochemical characteristics of water samples, and sediment taken from the farm and reference sites was determined. This study can aid in decision-making for a cage aquaculture production that is sustainable.

CHAPTER 2. LITERATURE REVIEW

2.1. Cage fish farming

The cage culture practice was firstly invested in southeast Asia since 1800, especially in Kampuchea's freshwater lake and river systems [10]. Today there are many species of fish cultivated in ponds and cage aquaculture around the world. Fish cultivated may vary from one country to another based on the climate of the country [10]. In 1950 Japan begin marine fish farming in cages. In1970 Thailand started cage culture techniques by growing two species of fish such as: sea bream and grouper. In 1980 Malaysia established large scale cage farming. Korea started cage culture at the end of 1980 [10]. Aquaculture was introduced in Africa by colonial government since 1940 as pond aquaculture practice specifically in South Africa, Uganda, Zambia, Zimbabwe, Ghana, Kenya, Malawi, Rwanda, Zambia, and Ghana. When we compare fish culture in cages to traditional pond systems, the fish culture technology in cages has greater advantages since it can provide more benefits by raising a lot of fish in a little amount of water [11]. In Rwanda, fish cage culture was introduced in 2000 and yields between 50 - 150 kg per m^3 in 6-9 months [1]. Due to its strong tolerance for poor water quality and low dissolved oxygen, the Tilapia cage cultured species was chosen in Rwanda [1]. Rwanda promotes cage fish farming to expand household incomes and national food security [12].

2.2. Environmental concerns in cage fish farming

Environmental problems associated with cage fish farming include alterations in water quality brought on by uneaten fish food and excretion which changes chemistry that make-up of benthic sediment, and increase risk of illness spread from viruses, parasites, and bacteria from wild fish to farmed fish [13].

2.2.1. Eutrophication

This is an increase of high concentration of dissolved nutrients like nitrogen (N) and phosphorus (P) that change the structure of ecosystem such as: algae blooms and aquatic plant that led to oxygen depletion, and deteriorate the water quality and other effects that cause deficiency of other water user [14]. The concentration of nutrients around cages may be sufficient to cause local eutrophication (Figure 3). However, carp and tilapia were strong tolerance for low water quality circumstances.

In Philippines, Lake Taal that have high stocking densities of cage and high feeding rates, there have been reports of fish deaths brought on by self-contamination of cage culture activities [13].

Figure 4: Algae bloom growing inland cage culture farm *[15]*

Algal blooms reduce light penetration, leading to plant die-offs in shore zones, and reduce the success of predators that depend on light to feed. Fish are killed during the summer when wind conditions are particularly low, causing reduced oxygen levels and higher amounts of toxic substance (Figure 4) [8].

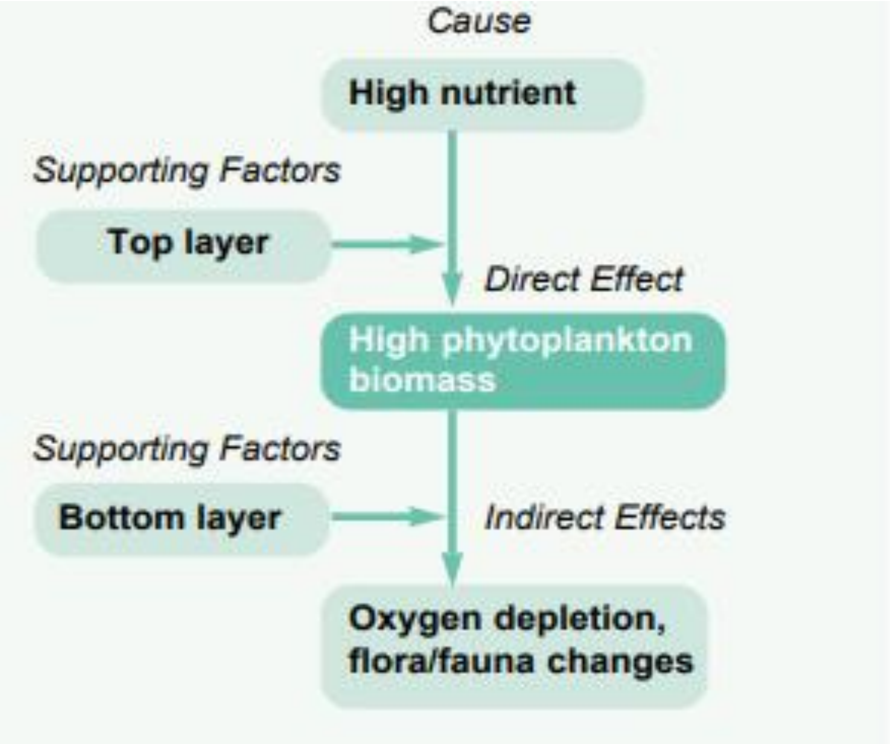

Figure 5:The process of eutrophication *[16]*

2.2.2. Water Quality

Water quality is a fundamental part of any cage fish farming system. It plays a big role in aquatic organisms, any decline in water quality stresses aquatic organisms, which has a significant impact on them. Fish and other aquatic organisms need good water quality conditions to survive and grow. Considering this, aquatic organisms' life process depends on the environment [7]. Fish farming in cages fed outside materials, means that constant supply of nutrients like nitrogen and phosphorus as well as proteins and carbon, can cause the water's quality deterioration. Successful fish culture practices rely on management of water quality [17]. In ecosystems, the quality of the water provides important information about the resources that sustain life. Physico-chemical factors, including temperature, Nitrate-nitrogen (NO_3-N), organic matter (OM), total nitrogen (TN), total carbon (TC), dissolved oxygen (DO), total phosphorus (TP), ammonia-nitrogen (NH_3), and total nitrogen (TN) are indicators of the impact of water quality. To determine the extent and source of any pollution, these parameters must be assessed and monitored [7].

2.3. Parameter of water quality

2.3.1. Temperature

Temperature of water is a controlling feature for all aquatic life because it can determine where in the water certain plants and animals can live. The temperature affects biochemical processes that occur in water. It is the most significant external factor affecting the ecosystem's ability to support life. Different species of organisms in aquatic system vary with temperature [18]. Climate change may affect water temperatures therefore participating in the survival of living organisms in ecosystem. Water temperature can also come from anthropogenic sources.

Water discharged from aquaculture, sewage lagoon or from pond will be warmer than the water it is supposed to mix with in a lake or river. This can result in warmer temperatures which affect animal and plant in the lake [19].

2.3.2. pH

pH values between 6 and 9 are acceptable for fish culture. [7]. The carbon dioxide is removed by photosynthesis during the day this causes the pH rises as the concentration of carbonic acid decreases during the day. The pH level drops at night as respiration produces carbon dioxide and photosynthesis stops. The pH range for protecting aquatic life is between 6 and 8 [20]. The pH in fish cage culture drops as result of accumulation of uneaten feed and waste deposits.

The pH values decrease when the depth increases. The lower pH values are caused by the aquatic animals' respiration as well as the breakdown of organic material from uneaten food and metabolic waste [21].

2.3.3. Dissolved Oxygen (DO)

Dissolved oxygen is a crucial criterion for determining water quality because it can influence the chemical, physical, and biological activities that might take place in the water. The presence of DO in water is an indicator of pollutant in water bodies. DO is important in water bodies and support life. DO has high range during the rainy season due to mixing of water [22]. The concentration of DO in water depends on the temperature, salinity, wind, pollutant run off, photosynthesis and respiration. As organic matter from uneaten feed and metabolic waste decomposes, microorganisms consume DO, resulting in a lower level of DO in cage fish farming [23].

Oxygen levels in the water around caged fish are decreased because of their respiration and the breakdown of organic matter. Due to great rank deterioration of organic matter, constrained water flow, and high temperatures, dissolved oxygen values were significantly lower in the summer. In cage culture there is a problem of water quality due to lower dissolved oxygen [7].

2.3.4. Electrical conductivity

Electrical conductivity is the term used to describe a substance that has ability to let an electric current pass through it. The ability of water to conduct electric current depends on charged molecules present. The unit of electrical conductivity is micro siemens per cm (μS/cm). In fish culture and downstream electrical conductivity is high because there is high accumulation of inorganic matter from uneaten feed and metabolic waste. The electric conductivity can be measured using an electrical conductivity meter (EC meter) [24].

2.3.5. Turbidity

Turbidity is the parameter used to assess clarity of water (transparency). Turbidity is brought by suspended particles that not allowing light to pass straight through the water and cause dissipating and absorbing light beams. A higher turbidity indicates more particles and dirty water. Low turbidity is a sign of clean water [7, 17]. The turbidity of water in cage aquaculture is high because there is high accumulation of organic matter and dissolved solid that change color of water. Turbidity is expressed in Nephelometric Turbidity Units (NTU). Modern instrument used to measure turbidity is called turbidimeters [25].

2.3.6. Total dissolved solids

The materials that are present in the water as dissolved solids are known as total dissolved solids (TDS). Inorganic salts and other dissolved substances make up the total dissolved solids. TDS levels in tap water and natural mineral water can range from 100 to 200 mg/L. The total dissolved solid will be high in places where the concentration of minerals is high. A report reveals that the TDS value is extremely high during the summer due to excessive water loss from evaporation and a rise in the concentration of salts in the water [26].

2.3.7. Hardness

The presence of calcium and magnesium bicarbonates and carbonates for temporary hardness or sulphates and chlorides for permanent hardness determines water's hardness. Water containing 0 to 75 ppm $CaCO_3$ is referred to as soft water, because it has the smallest buffering capability. Hardness of water is expressed in mg of $CaCO_3$/L [7]. The main contributors to water hardness are dissolved polyvalent metallic ions from sedimentary rocks and discharges from soils. The two main ions that are found in many sedimentary rocks are calcium and magnesium. Magnesium and calcium are two more crucial mineral components of meals. In addition to the ions mentioned above, other polyvalent ions including barium, aluminum, iron, strontium, manganese, and zinc also make contribution to the overall hardness of water [26].

2.3.8. Chemical Oxygen Demand

The chemical oxygen demand (COD) is the amount of oxygen necessary for the oxidation (decomposition) of organic matter present in each volume of water. The chemical oxygen demand can be used to assess whether organic compounds are present in water. COD is frequently employed as a gauge of how sensitive the organic and inorganic components found in water bodies, sewage effluents, and industrial units are to oxidation. As both inorganic and organic matter concentrations rise, COD also rises. The COD unit of measurement is mg/L, or mass of oxygen consumed over volume of solution [27].

2.3.9. Alkalinity

Alkalinity is the property of water to withstand pH changes that would make it more acidic. Surface water with higher levels of alkalinity will regulate aquatic life against pH variations that are harmful by acting as a buffer for acidic pollutants like acid rain.

Alkalinity influences cleaning systems such anaerobic absorption, hence it is vital to take this into account when treating wastewater and drinking water [28]. To determine the effectiveness and conditions of water bodies, total alkalinity may be used as a technique. The pH range needed for fish and aquatic life is 6.0 to 9.0 because alkalinity protects living things from pH changes by acting as a buffer. [29].

2.3.10. Nitrite-Nitrogen (NO_2-N)

In the process of oxidizing NH_3 or NH_4^+ into NO_3, nitrite serves as an intermediate molecule. The highly aerobic bacteria that are present in the system naturally carry out this nitrification process. Less than 0.3 mg/L of nitrite is the preferred level for aquaculture. Nitrite-N concentrations in cage culture systems varied between 0.001 and 0.28 mg/L during investigations [7].

2.3.11. Ammonia-Nitrogen (NH_3-N)

NH_3-N is the waste created by aquatic animals, through metabolic excretion. The research estimated that ammonia was much at the cage fish culture site due to metabolic waste excreted by the fish. According to study, ammonia concentrations of greater than 0.2 mg/L are bad for fish farming and less than 0.05 mg/L are safe concentrations for freshwater fish farming. If there is no water circulation through the cage, the large volume of uneaten feed and metabolic waste lowers the amount of dissolved oxygen and increases the concentration of ammonia in the cage and the area around the cage [17].

2.3.12. Phosphate-Phosphorus (PO_4-P)

One of the most important minerals for the nourishment and growth of living things is phosphorus. dissolved phosphate is how phosphorus appears in natural and wastewaters. The most stable form of phosphate is orthophosphate, but polyphosphates in water are unstable and transform to orthophosphate. The concentrations of phosphorus in water bodies usually can be reduced by plants during absorption or adsorption by metal oxides in the sediment [30]. Both natural and man-made sources of phosphates can pollute surface water and groundwater. Phosphorus is naturally obtained from a variety of sources, including air deposition, weathering of soluble inorganic elements, natural mineral and rock deterioration, runoff, decomposing biomass, and sedimentation.

Fertilizers, sewer waste, animal waste, detergents, factories runoff, phosphate mining, and fires in forests are just a few examples of phosphorus sources that are caused by humans that contributes to the pollution of water body. The ecosystem does no affected by naturally occurring phosphate concentrations.

Eutrophication can result from high phosphate levels in water bodies. Phosphorus is the primary byproduct of the fish farm that has an effect on the ecology of the lake. Through fish feed, phosphorus from cage farming may penetrate the aquatic ecosystem. Area around the cages contain high amount of Phosphorus can cause problems to the aquatic environment due to high levels of phosphorus. The accumulation of labile phosphorus is due to decomposition of solid waste releases in water column [13].

2.3.13. Total Suspended Solids (TSS)

They are characterized as being made up of particles that are too big to get through the filter that separates them from the water. Suspended solids in high concentrations may settle to the bottom of the lake and cover aquatic or macroinvertebrate life. This coating can prevent adequate oxygen transfer and cause the death of hidden life [31]. Because a large concentration of suspended solids in water alters the color of the water this parameter would be the most important measurement, reduce oxygen required by aquatic organisms by consuming it during decomposition and inhibit the penetration of light in water. High suspended solids buildup will prevent light from penetrating, which will inhibit the photosynthetic activity of phytoplankton, algae, and macrophytes. The cage culture site's increased TSS value was influenced by extra fish feed and fish waste [7].

2.4. Effect of cage fish farming in the sediment

Fish farming waste that has accumulated below the fish cages can lead to organic enrichment of sediment, decreased oxygen levels in sediment (anoxic conditions), and the development of methane and hydrogen sulfide, which can be a danger to benthic ecosystems [32]. Even though aquaculture provides humans with a reliable and high-quality source of food, it also raises serious environmental concerns because it releases a lot of organic waste into the environment, like unfinished fish feed and metabolic waste. In organic-rich sediments, oxygen is rapidly depleted within a small portion of the surface sediment, and anaerobic microorganisms dominate organic carbon oxidation through denitrification [33]. The environment may undergo chemical, physical, and biological changes as a result of the increased discharge of organic and inorganic pollutants from aquaculture, including alterations to water bodies and sediment. [34].

2.5. Sediment quality parameter

2.5.1. Total Organic Matter (TOM)

Total Organic Matter (TOM) is a crucial sediment metric and the main food supply for benthal organisms, which are necessary for the sediment's structure and composition. Depends on the quantity of organic matter released in the sediments will lead to contamination [35].

2.5.2. Total organic carbon (TOC)

TOC is the amount of organic matter present in the sediment and used as an indicator of pollution with respect to how many hydrocarbons the sediment may generate. Large volumes of organic and inorganic waste produced by cage fish rearing in the form of excrement and non-ingested feed. Marine ecology would be impacted by the increased influx of organic components, leading to eutrophication in sediment and water. The major source of organic carbon in the sediment was the frequency addition of food in cages fish farm [36].

2.6. Effect of cage fish farming in greenhouse gases emissions

Using fossil fuels like coal, oil, gas, and fossil fuels for energy, as well as deforestation and forest degradation that emit greenhouse gases (GHGs) into the atmosphere, humans are acknowledged as the primary cause of climate change. The expanded aggregation of fluorinated gases Carbon dioxide (CO_2), methane (CH_4), nitrous oxides (N_2O), and Carbon dioxide (CO_2) are examples of GHGs released in the environment has been connected to these human activities (Figure 5) [37]. As fish feed is protein rich, the leftover feed and fecal matter are the ultimate sources for the release of greenhouse gases during microbial mineralization. Therefore, the aquaculture sector is also responsible for global warming by emitting greenhouse gases. Different world organizations are conducting research for quantifying GHGs from the aquaculture sector and its possible mitigation [38].

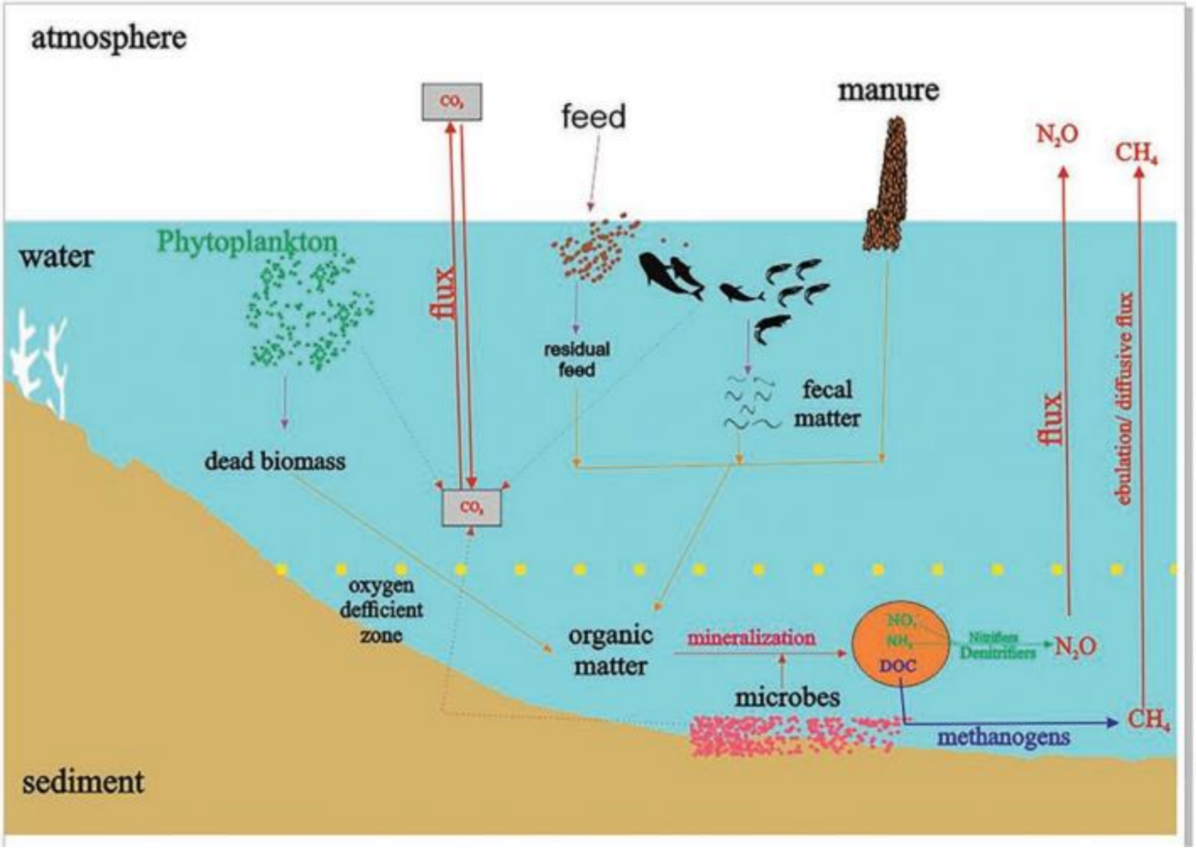

Figure 6: Biochemical processes leading to greenhouse gas emissions from cage aquaculture *[38]*

2.7. Greenhouse gas emissions from aquaculture systems

2.7.1. Carbon Dioxide (CO_2)

The respiration of biological components (fish, phytoplankton, benthic creatures, and microorganisms), as well as the mineralization of organic materials, is the source of CO_2 generation in aquaculture systems. When organic materials are mineralized by heterotrophic bacteria mostly create CO_2. The main sources of organic materials are feed residues and fish feces. Many aquaculture systems contain dead phytoplankton biomass and manure inputs that increase the organic matter content. The emission of CO_2 depends upon many factors like air and water temperature, pH, rate of algal productivity and partial pressure of CO_2 in water and surface atmosphere [39].

2.7.2. Methane gas (CH_4)

Methanogenic bacteria produce methane gas by using dissolved organic carbon (DOC) in absence of oxygen (anaerobic condition). In fishponds aquaculture systems, the bottom sediment is the major site for methanogenic bacteria activity as it exists as less aerated site of the pond environment. Methanogenic bacteria using DOC for energy production. The DOC resulting from mineralization process of organic matter by heterotrophic bacteria (micro/macro-benthic organisms) found in sediment and some extent from the metabolic waste of fish [40]. The emission of methane gas from aquatic systems to the atmosphere occurs in two ways the first is ebullition of gas bubbles, the second is diffusion. Methane flow from the aquaculture system depends on water, air, and temperature, which indicates that CH_4 emission relates to the water thermal regime. The methanogenesis process is accelerated by rising temperatures, which increases CH_4 emissions [38]. There is seasonal variation of CH_4 emissions, the emissions being greater in summer and lower in winter, autumn and spring. The production of methane depends on the dissolved oxygen concentration of the aquaculture system because aerobic condition inhibits the activity of methanogens [41].

2.7.3. Nitrous Oxide (N_2O)

Nitrous oxide produced by nitrifying and denitrifying bacteria through autotrophic aerobic nitrification, and anaerobic denitrification process. These bacteria use ammonia, which is released from the degradation of uneaten feed and metabolic waste of fish. Photosynthetic algal also releases NO_3^- and dissolved oxygen, which in hence the production of N_2O from nitrification and denitrification process [38]. pH plays a great role in the production of nitrous oxide in cage aquaculture and sediment. The acidic condition of sediment inhibits the reductase activity of N_2O by preventing further oxidation (denitrifies) which causes the emission of more N_2O during denitrification (Figure 6) [42].

Figure 7:Tthe process of nitrification and denitrification *[42]*

CHAPTER 3. MATERIALS AND METHODS

3.1. Sampling locations

This study was done in Lake Kivu as shown in figure 7. Lake Kivu is about 50 km wide and 42 km long. It is the eight biggest lakes in Africa according to statistics, with a total surface area of 2,700 km^2. The surface of the lake sits at a height of 1,460 m. The lake is the eighteenth deepest lake in the world by maximum depth of 485 m and a mean depth of 240 m. The lake's surface is 1,460 meters above sea level. Lake Kivu has island called" Idjwi" which is the tenth-largest island in the world. Settlements on the lake's shore include Bukavu, Kabare, Kalehe, Sake and Goma in the Democratic Republic of the Congo, and Rubavu, Karongi , and Rusizi in Rwanda.

In this study three sampling sites were selected such as Kigufi (in the cage and out of the cage), Nyamwenda, and hot spring as reference. After selecting sampling site was divided into sampling point include: ten sampling points at Kigufi site (5 in the cage and 5 out of the cage in 100 m away from the cage), four sampling points at Nyamwenda, and 3 sampling points in hot spring (figure 8) [4].

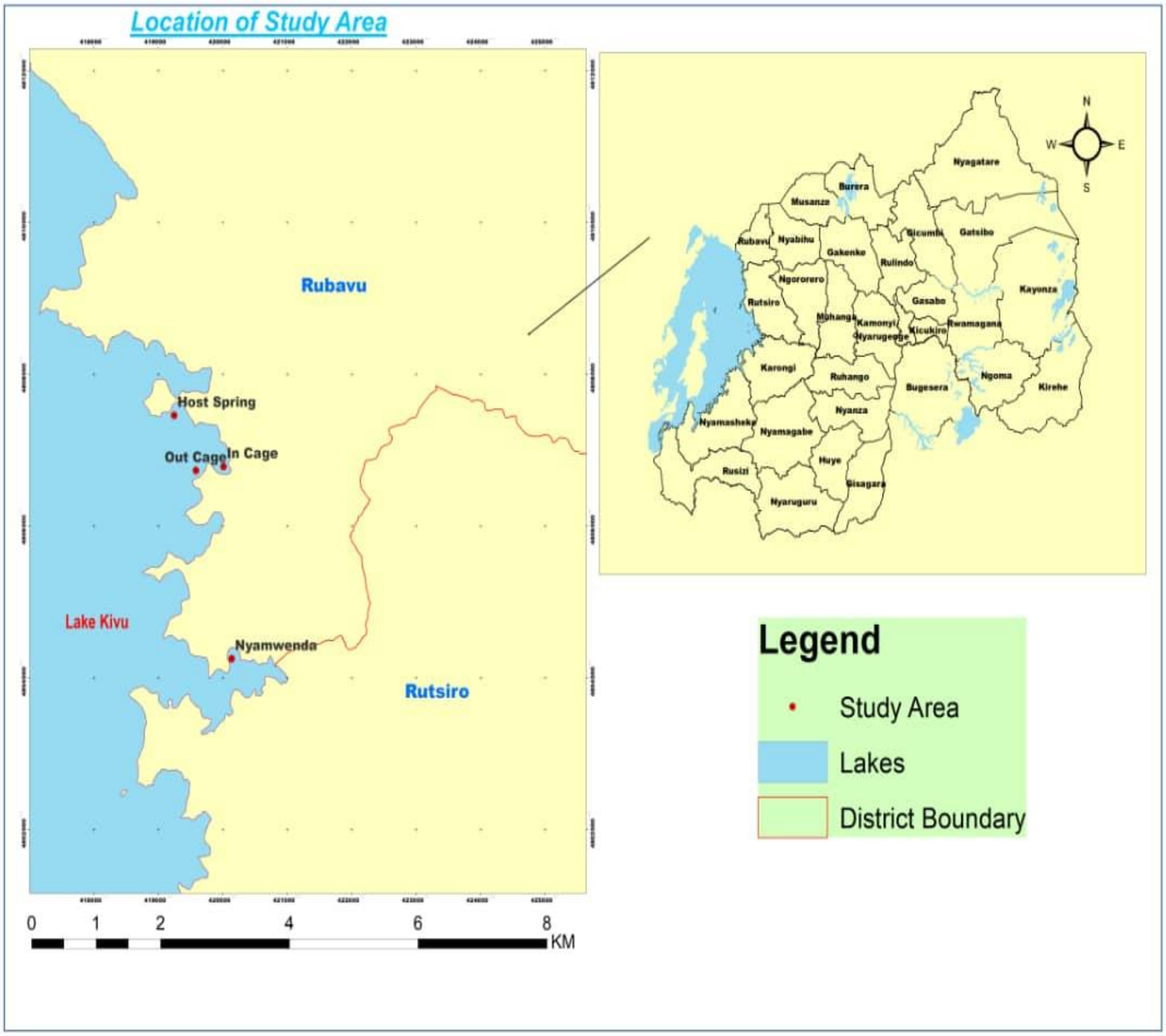

Figure 8:Map of Lake Kivu showing sampling site of this study.

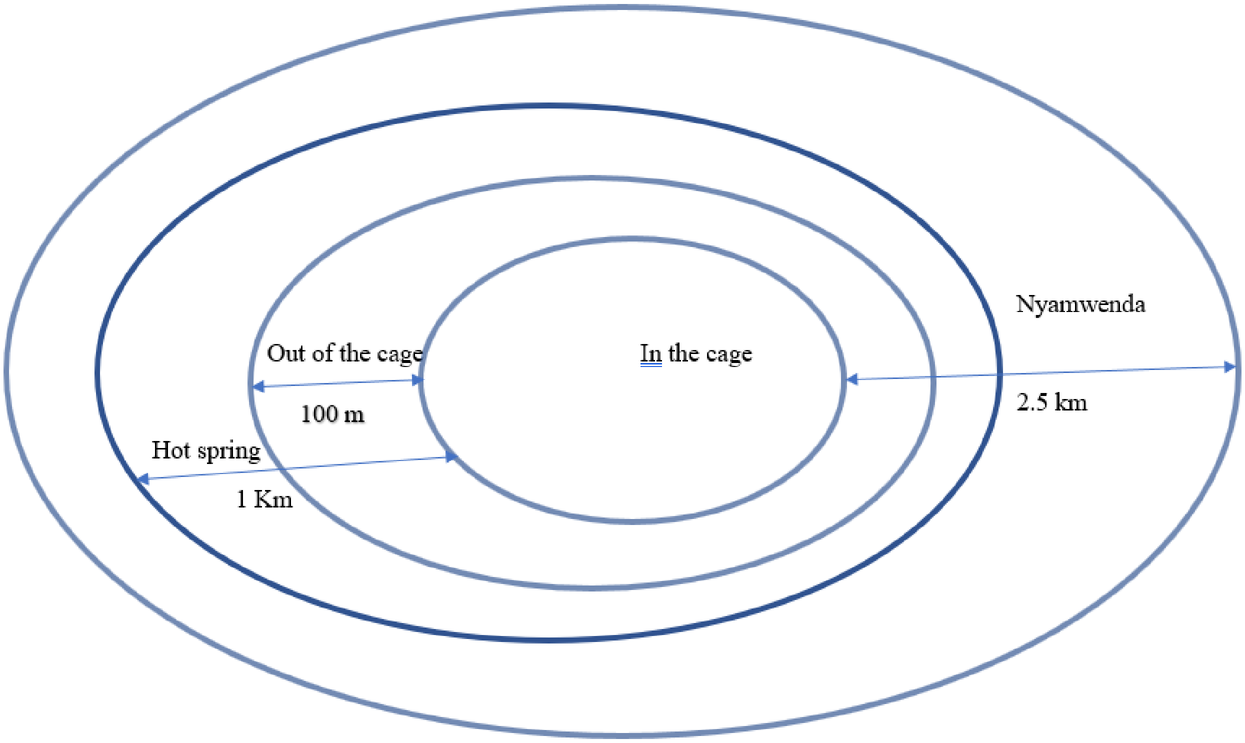

Figure 9: Distance between sampling station

3.2. Sample collection

The samples were collected in the three months October from 11- 13/ 10/2022, November from 8-10/11/2022 and December from 6-8/12/2022 in Lake Kivu. Every month, water samples were taken at various depths 3±1 meters in the surface water, 9±6 meters in the middle, and 16±7 meters at the bottom (Figure 9). At each sampling point using a Niskin bottle and transfer to a 1 L plastic bottles for laboratory analysis into chlorophyll a, and TSS. In the laboratory, water samples were filtered using Whatman filter paper and vacuum pump to increase pressure for filtration of chlorophyll a, and TSS. The nutrient samples were filtered in the field immediately after sampling and HCl acid was added for sample preservation until the laboratory analysis was done. The bottles were acid washed and rinsed with distilled water before sampling to avoid any contamination, after collection of the water sample each bottle was stopped and labelled with full details of the site, time and date of collection and transported in a cool box to the laboratory analysis [43].

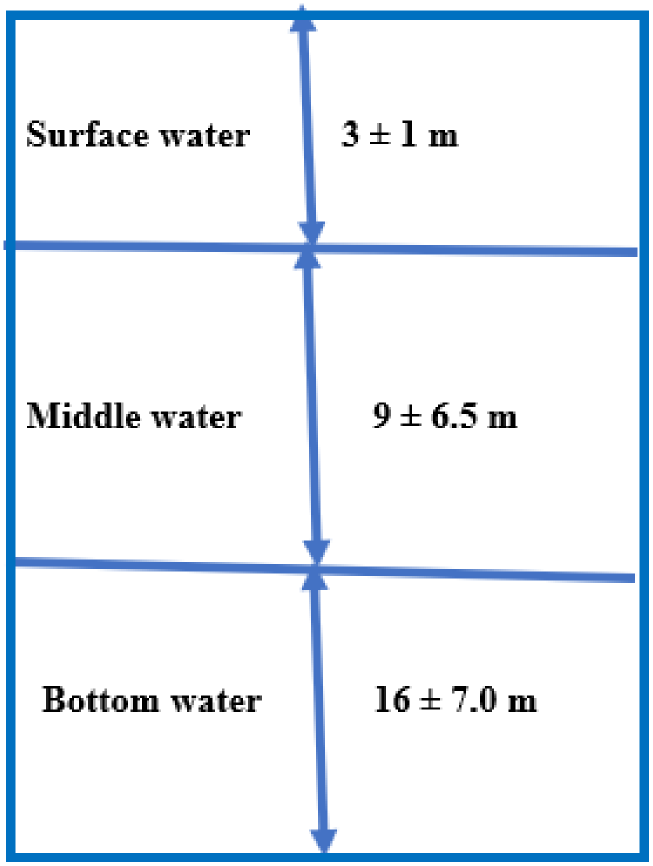

Figure 10: Sampling profile level

3.3. Water quality determination

3.3.1. Field determination

Echo sounder was used to determine the depth of water. Secchi disk was used to examine clarity of water. Based on standardization methods for the analysis of water and wastewater.

3.3.2. Laboratory analysis

The following are laboratory physico-chemical parameters examined in water: nitrate-nitrogen, ammonium-nitrogen, chlorophyll a, phosphate-phosphorus and total suspended solid. water qualities were analyzed using standardization methods for the analysis of water and wastewater [44].

3.3.2. 1. NO_3^- and NH_4^+concentrations

Samples were stored in the refrigerator at 4°C before the beginning of laboratory analysis. NH_4-N and NO_3-N were both analyzed using a UV-Visible spectrophotometer at absorbances of 660 nm and 540 nm, respectively. For NO_3-N, 100 L of blanks, standards, and collected water samples were pipetted, followed by the addition of 100 L of vanadium (III) chloride solution for the reduction reaction, and 100 L of the Gries reagent—sufanilic acid and N-(1-Naphthyl)-ethylenediamine dihydrochloride to create color. Samples whose absorbance was higher than the detection threshold were diluted to within-range levels. The sample concentrations were calculated using the dilution factor, which was recorded. A total of 100 L of standards, blanks, and samples were pipetted for the NH4-N analytical concentration. Followed by addition of 50 mL of the colorant (Sodium salicylate solution), 20 mL of the oxidation solution (Dichloro isocyanuric acid sodium salt) was added. The reaction was let 30 minutes to complete itself before the absorbance at 660 nm was measured [44].

3.3.2. 2.PO_4^{-3} concentration Water

After accurately measuring 15 mL of the filtered water sample, Ammonium molybdate (3 mL) and hydrazine sulphate (2 mL) were added, and the mixture was kept in a water bath for 30 minutes. UV-Visible spectrophotometry was used to measure the blue color that was observed.

3.3.2. 3.TSS (Total suspended solid concentrations)

The water samples were filtered in the laboratory and volume of filtered water recorded after filtration the papers were kept in closed petri dishes a waiting for analysis. To obtain constant weight samples were oven-dried at 103°C overnight.

The calculation was done using equation [26].

TSS (mg/L) = (Wc - Wf) x10^6) / V (Equation 1)

Where TSS = Total suspended solids, Wc = Constant weight of filter + residue in grams, Wf = Weight of pre-combusted filter in grams; V = Volume of filtered water sample used in mL.

3.3.2.4.Chlorophyll analysis

The filter paper with chlorophyll was taken and put in a tube. 10 mL of 80% of ethanol was added and closed the tube. Then put the tube was heated in water bath (75^0C) for 5 min and leave it. The tubes were put in centrifuge after centrifuging for about 2 min, was decanted some of the clear liquid was measured using a UV-Visible spectrophotometer. The spectrophotometer was calibrated using 80% of ethanol as a blank solution. The correct wavelength (750 nm) was set. The cell containing the reference solution of ethanol was placed in the cell holder. The sample compartment lid was closed. The value of absorbance was displayed in the readout. The extinction of the extract both at 750 nm (E_O) and at 665 nm was determined. Subsequently 0.05 mL HCl (0.4 mol/L) was added to 5 mL extract. After 5 min was measured again, the extinction at 750 nm (E_{Oa}) and at 665 nm (E_{Xa}) [45].

Calculation

Chlorophyll a in units of µg/L is calculated as:

$$Chl.a = \frac{26.7[(E665-750)b-(E665-750)a]^{x}v(Al)}{\mathrm{VL}} \quad \text{(Equation 2)}$$

With

(E665-750) b = 665 nm absorbance before acidification minus 750 nm absorbance

before acidification.

(E665-750) a = 665 nm absorbance before acidification minus 750 nm absorbance after-acidification.

V = filtered sample volume [L],

L = Cuvette path length [cm],

V(ac) = Volume of 99.9% alcohol used in the extraction [mL]

3.4. Sediment sampling and analysis

Sediment samples were taken with an Ekman grab sampler from beneath cages and at the control sites, then sealed in plastic bags, kept cold, and sent to the lab for analysis [4]. Loss of ignition was used to measure total organic matter. The first procedure involved placing the cup in an oven set to 105°C for 15 minutes, allowing it to cool in a desiccator for 20 minutes, and then weighing as (b). To get the fine sediments, the sediment samples were sun dried and sieved through mesh measuring 2 mm and poured into a cup, placed in oven for 24 hours at 105°C, chilled in a desiccator for 15 minutes, weight was recorded as (a). The dried sample was weighed as (c) after being combusted for three hours in a furnace at 550°C and chilled for 30-60 min in a desiccator. The following formula was used to calculate organic matter:

$$Organic\ matter\ content(\%) = \frac{\mathrm{a-c}}{a-b}\times 100 \text{ (Equation 3) [46]}$$

3.5. Statistical analysis

Analysis of variance (ANOVA) was used to compare the various physicochemical parameters assessed at the farm with the reference location to see whether significant variations have taken place. To compare the differences between groups according to sample time, a one-way ANOVA was performed. Descriptive statistics was used to determine the mean, range, and standard deviation for the various parameters. Probabilities of $p < 0.05$ were considered significant [4]

CHAPITER 4. RESULTS AND DISCUSSION

4.1. Depth of Lake

The study area's water quality parameters' mean and standard deviation are shown in figure 10 below. The mean depth along the cages site was 19.8 ± 3.8 m and 23.8 ± 7.0 m out of the cage in October showing that less materials deposited. The average depth along the cages site in November was 23 ± 5.7 m slightly increased compared to 26 ± 5.0 m out of the cage showing that less deposition of materials and mean depth along the cages site in December was 24.4 ± 4.7 m and 26.5 ± 6.5 m out of the cage showing that less deposition of materials figure (11,12).

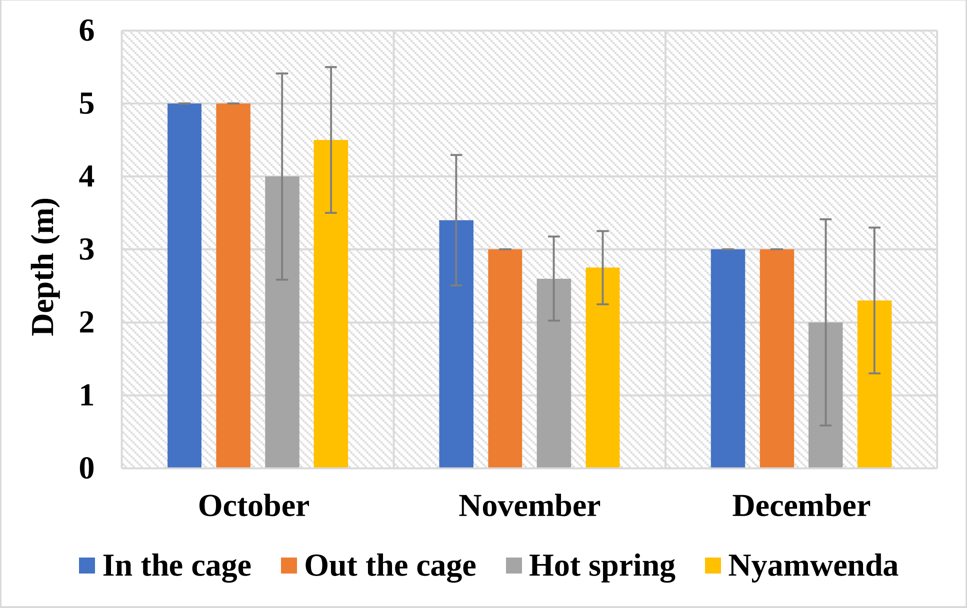

Figure 11 : Depth in (m) of surface water in Lake Kivu

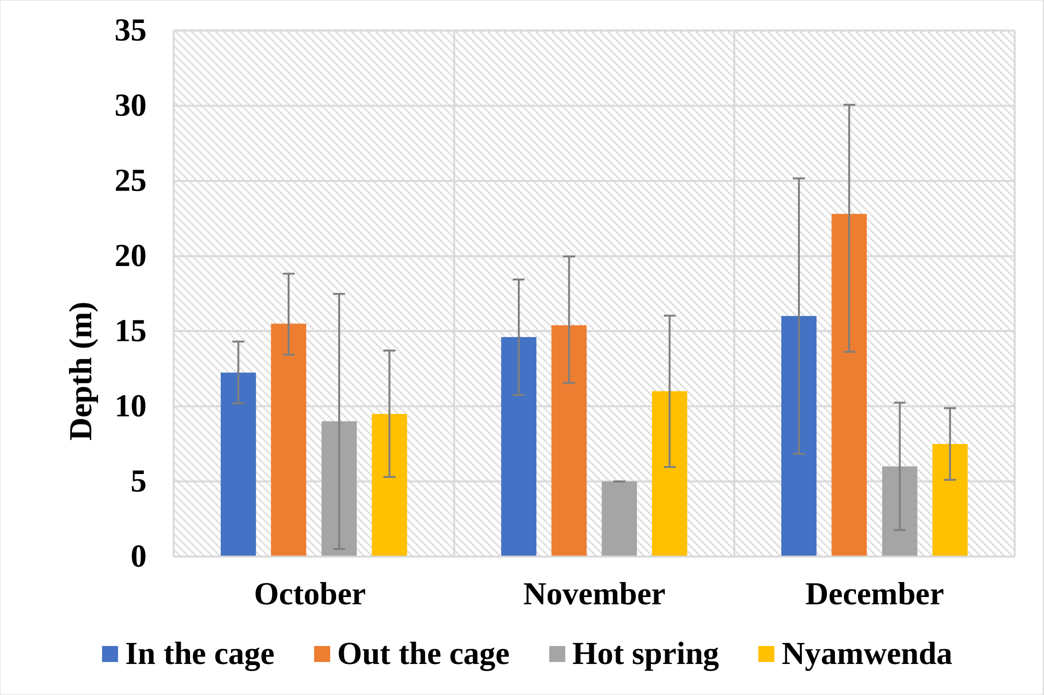

Figure 12: Depth in (m) of middle water in Lake Kivu

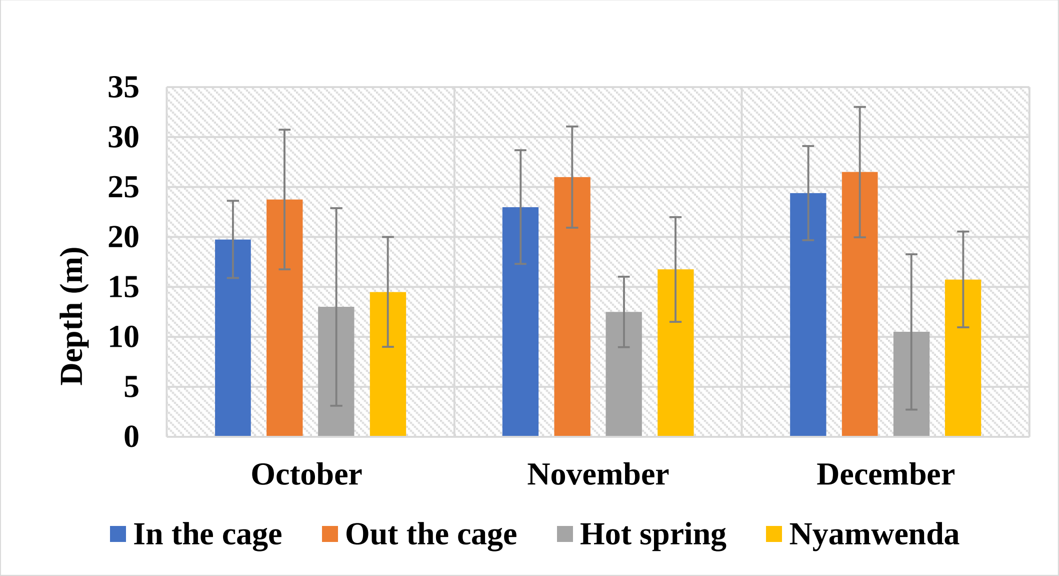

Figure 13: Depth in (m) of bottom water Lake Kivu

4.2. Ammonium-nitrogen (NH_4-N)

Agricultural activities, Municipal wastewater, excretions from animals are sources of ammonia in the aquatic environment. When ammonia is present in sufficient amounts in the water, aquatic organisms have difficulty excreting it adequately. This may cause toxic accumulation in blood and internal tissues, which may potentially cause death. Ecological variables, like pH and temperature, can influence alkali harmfulness to Lake creatures [47].

Ammonium-Nitrogen (NH_4-N) content average value of the lake surface water in October, was 9.72 µg/L, 14.10 µg/L, 2.16 µg/L and 12.57 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the NH_4-N value at the cage and control sites (*p=0.522*). In November, the determined value for NH_4-N was 8.80 µg/L, 21.13 µg/L, 9.19 µg/L and 11.00 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the NH_4-N value at the cage and control site (*p=0.718*). In December the determined value for NH_4-N was 58.29 µg/L, 49.45 µg/L, 15.31 µg/L and 22.86 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively [30]. No statistically significant difference existed between the NH_4-N value at the cage and control site (*p=0.10*) (Figure 13) [48].

NH_4-N content average value of the lake middle water in October, were 3.88 µg/L, 9.94µg/L, 5.12 µg/L and 11.36 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the NH_4-N value at the cage and control site (*p=0.670*). November was 21.13 µg/L, 13. 68µg/L, 8.32 µg/L and 8.90 µg/L from the cage, out of the cage, hot spring, and Nyamwenda respectively. No statistically significant difference existed between the NH_4-N value at the cage and control site (*p=0.502*). In December, the determined value for NH_4-N was 48.22 µg/L, 48.13 µg/L, 2.63 µg/L and 10.50 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively [30]. The difference in NH_4-N values between the cage and the control site was statistically significant (*p=0.005*) (Figure 14).

NH_4-N content average value of the lake bottom water in October, were 1.40 µg/L, 17.17 µg/L, 6.00 µg/L and 12.89 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively.

No statistically significant difference existed between the NH_4-N value at the cage and control site. In November, the determined value for NH_4-N was 19.81 µg/L, 14.38 µg/L, 6.35 µg/L and 7.11 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the NH_4-N value at the cage and control site. In December, the determined value for NH_4-N was 46.43 µg/L, 35.44 µg/L, 18.78 µg/L and 46.16 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively [30]. No statistically significant difference existed between the NH_4-N value at the cage and control site ($p=0.412$) (Figure 15).

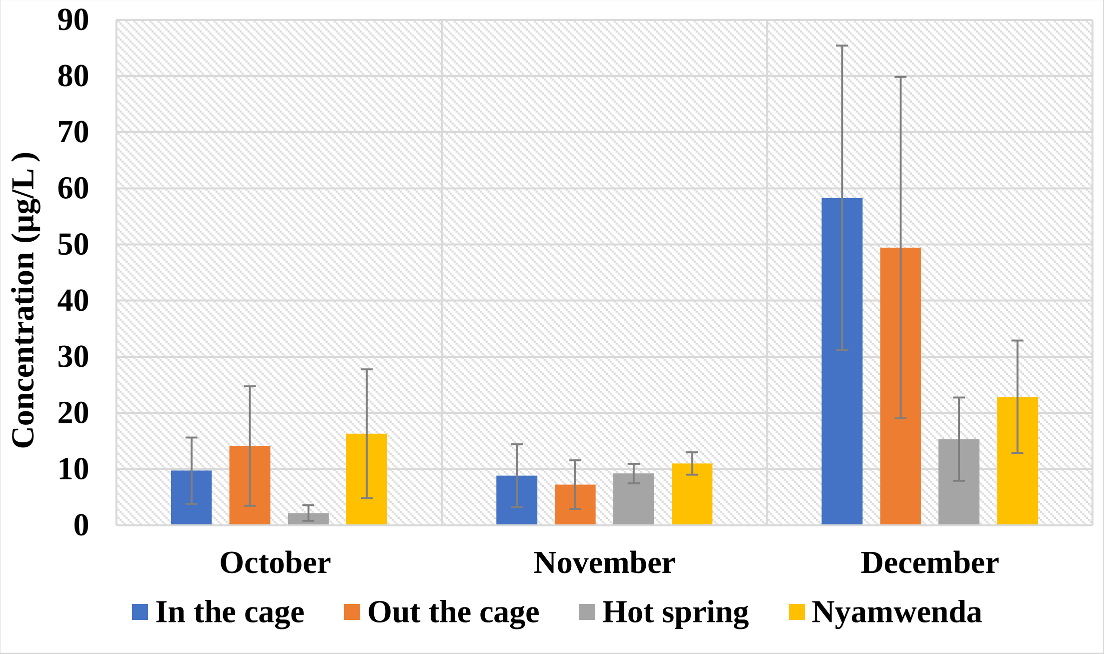

Figure 14: Concentration of Ammonium -nitrogen (NH_4 -N) in the surface water Lake Kivu

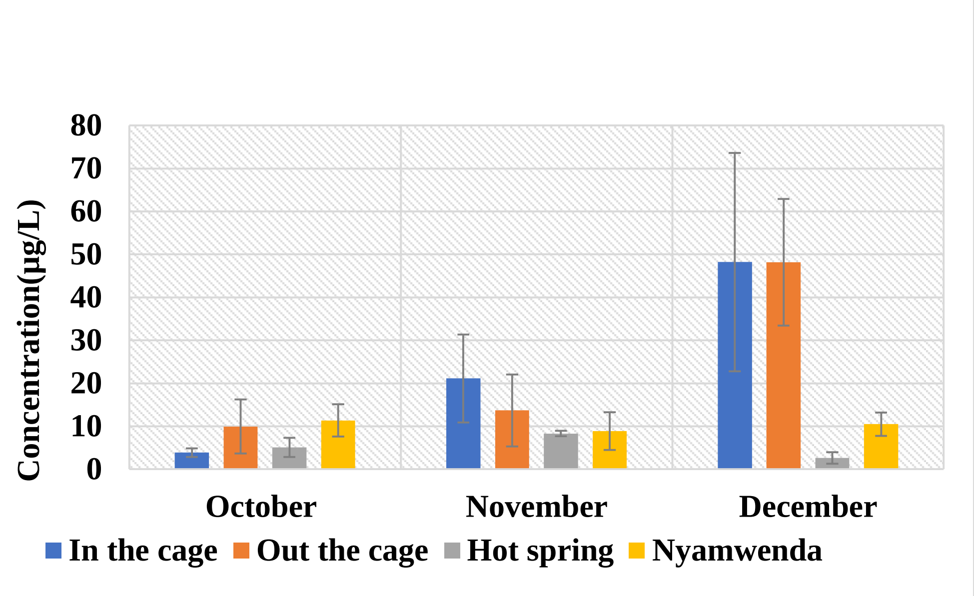

Figure 15: Concentration of Ammonium -nitrogen (NH4 -N) in the middle water Lake Kivu

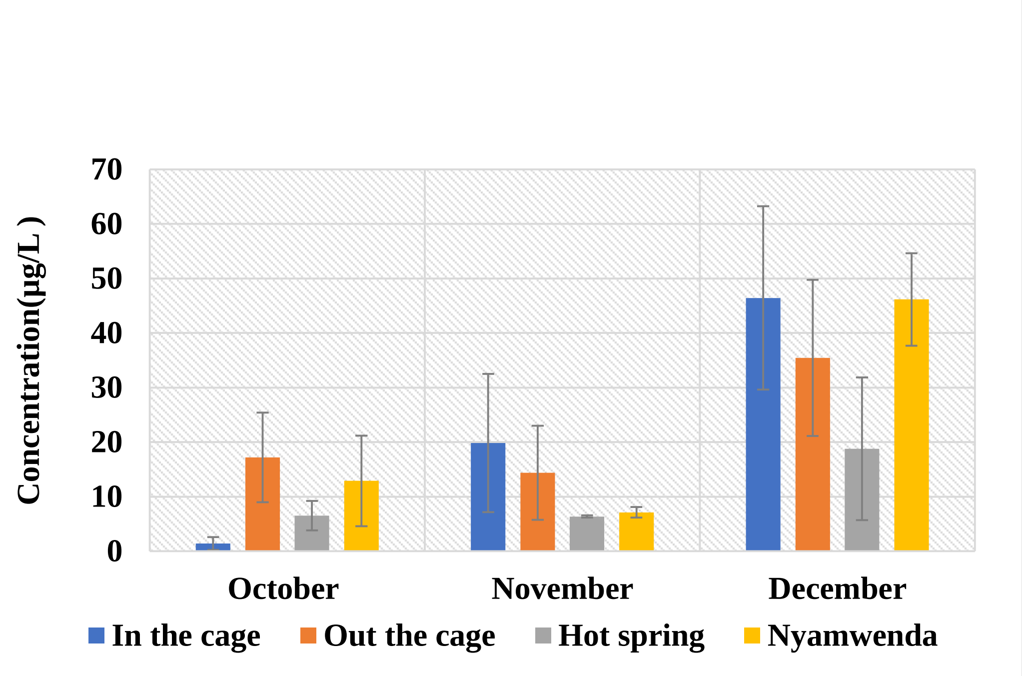

Figure 16: Concentration of Ammonium -nitrogen (NH_4 -N) in the bottom water Lake Kivu

Surface water total ammonia-nitrogen concentrations are typically lower in the dry season than they are in the winter. This is brought on by plant uptake and a reduction in ammonia solubility with increasing water temperature. The safe ammonia concentration for freshwater fish is less than

0.05 mg/L, according to Lawson, who also found that ammonia concentrations more than 0.2 mg/L are not acceptable for fish farming.

According to some reports, the ammonia content in the cage culture system varied from 0.01 mg/L to 1.15 mg/L [49]. This research conducted in Lake Kivu shows that ammonia concentration found was in the range of acceptable limit with refers to other report conducted by others [49].

4.3. Nitrate – Nitrogen (NO_3-N)

Any water body's nitrate concentration is a crucial indicator of the degree of eutrophication in the ecosystem. Agricultural field runoff, household runoff, and sewage are a few examples of natural sources of NO_3-N that end up in water bodies.

NO_3-N content average value of the lake surface water in October, the determined NO_3-N value was 59.21 µg/L, 115.03 µg/L, 198.37 µg/L and 270.31 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the NO_3-N value at the cage and control site ($p=0.155$).

In November, the determined NO_3-N value was 48.43 µg/L, 12.93 µg/L, 10.54 µg/L and 15.42 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the NO_3-N value at the cage and control site ($p=0.484$). In December the determined NO_3-N value was 82.4 µg/L, 84.8 µg/L, 138.66 µg/L and 136.33 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the NO_3-N value at the cage and control site ($p=0.102$) which is under the permissible limit of 50 mg/L according to WHO guideline (Figure 16) [30] .

Nitrogen content average value of the lake middle water in October, the determined NO_3-N value was 51.56 µg/L, 167.12 µg/L, 185.67 µg/L and 316.53 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the NO_3-N value at the cage and control site ($p=0.150$).

In November, the determined NO_3-N value was 20.14 µg/L, 16.08 µg/L, 2.83 µg/L and 17.87 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the NO_3-N value at the cage and control site ($p=0.619$). December was 78.8 µg/L, 92.26 µg/L, 150.33 µg/L and 138.66 µg/L from the cage, out of the cage, hot spring, and Nyamwenda respectively No statistically significant difference existed between the NO_3-N value at the cage and control site (*p=0.111*) which is under the permissible limit of 50 mg/L according to WHO guideline (Figure 17) [30].

Nitrogen content average value of the lake bottom water in October, were 84.92 µg/L, 242.48 µg/L, 166.79 µg/L and 152.47 µg/L from the cage, out of the cage, hot spring, and Nyamwenda respectively. No statistically significant difference existed between the NO_3-N value at the cage and control site (*p=0.461*). November was 74.18 µg/L, 56.25 µg/L, 19.98 µg/L and 19.33 µg/L from the cage, out of the cage, hot spring, and Nyamwenda respectively. No statistically significant difference existed between the NO_3-N value at the cage and control site (*p=0.319*). December was 102 µg/L, 140 µg/L, 148.66 µg/L and 46.16 µg/L from the cage, out of the cage, hot spring, and Nyamwenda respectively. No statistically significant difference existed between the NO_3-N value at the cage and control site (*p=0.016*) which is under the permissible limit of 50 mg/L according to WHO guideline (Figure 18) [30].

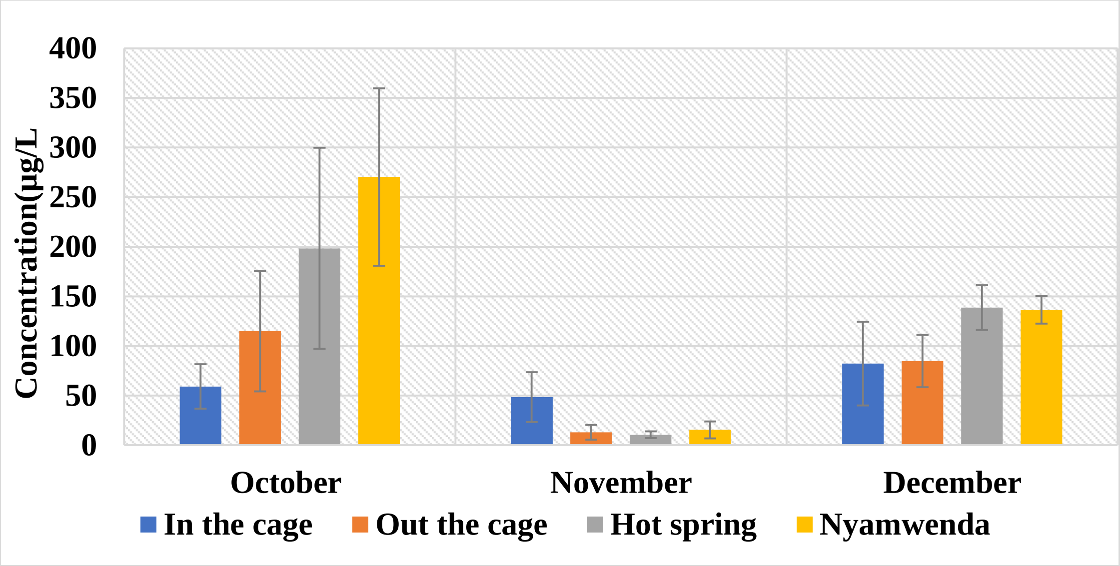

Figure 17: Concentration of Nitrate -Nitrogen (NO3 -N) in the surface water at Lake Kivu

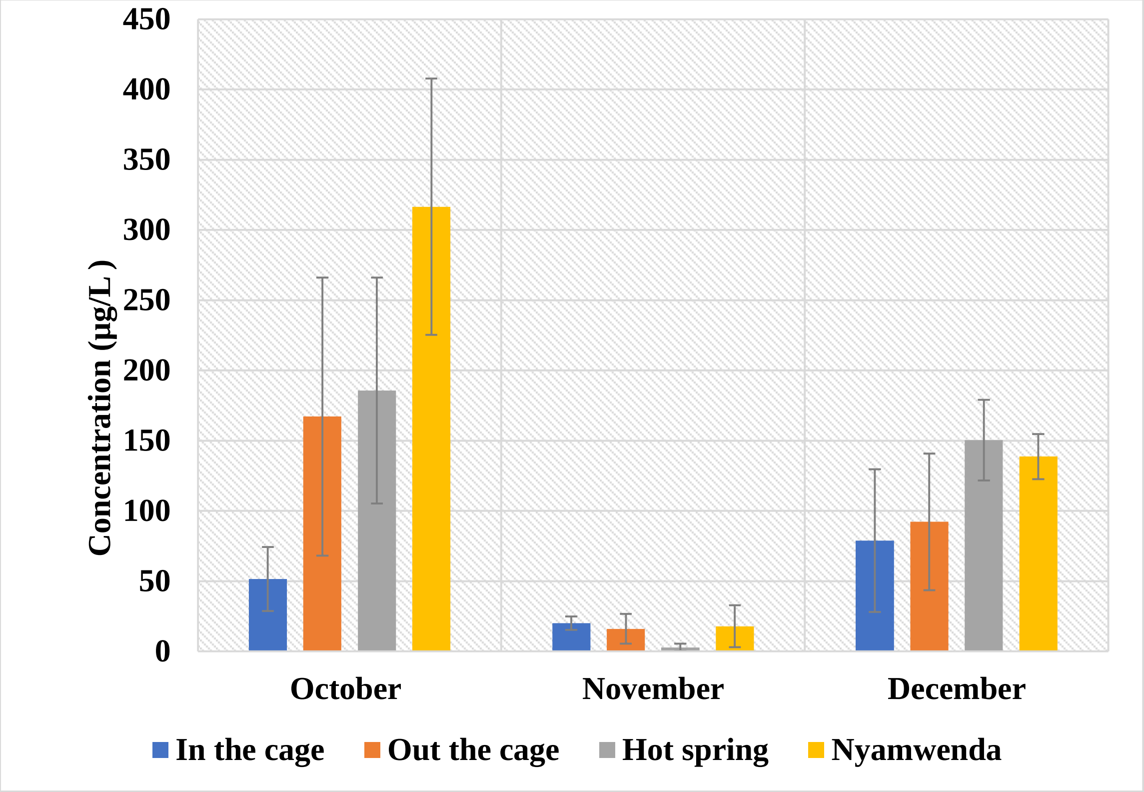

Figure 18 : Concentration of Nitrate -Nitrogen (NO_3-N) in the middle water at Lake Kivu

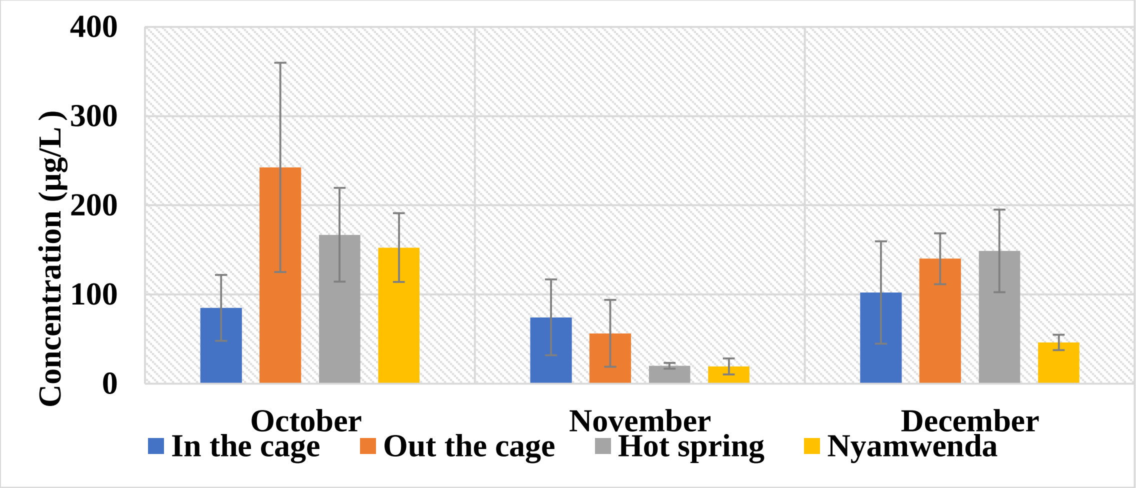

Figure 19: Concentration of Nitrate -Nitrogen (NO_3-N) in the bottom water at Lake Kivu

Nitrate levels in surface water can increase significantly due to agricultural overflow, rubbish dump overflow, or contamination with animal or human waste, however they usually range from 0 to 18 mg/L.

When the river flows by nitrate-rich sources, the concentration changes with the season and may increase [50]. According to results obtained Nitrate – Nitrogen (NO_3-N) in monitored area from the surface water to the bottom show that no contaminations. Also, according to Carlson assessment criteria Trophic Status of Lakes Nitrate-Nitrogen concentrations ranged from 0.3 mg/L for oligotrophic, mesotrophic range from 0.3 to 0.65 mg/L, Eutrophic range from 0.5 to 1.5 mg/L and, hypereutrophic >1.5 mg/L means that Lake Kivu was Oligotrophic (clear water and no productivity) as results show that nitrate-nitrogen concentration less than 0.3 mg/L [51].

4.4. Phosphate- Phosphorus (PO_4-P)

Phosphorus is a growth inhibitor and one of the essential nutrients for microorganisms and plants. The concentration of PO_4-P average value of the lake surface water in October, was 66.84 µg/L, 65.04 µg/L, 70 µg/L and 107.61 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the PO_4-P value at the cage and control site ($p=0.069$). In November, the determined PO_4-P value was 52.61 µg/L, 54.68 µg/L, 73.15 µg/L and 72.92 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively.

No statistically significant difference existed between the PO_4-P value at the cage and control site ($p=0.554$). In December, the determined PO_4-P value was 397.11 µg/L, 598.91 µg/L, 181.98 µg/L and 162.61 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the PO_4-P value at the cage and control site ($p=0.251$) which is under the permissible limit of 14 mg/L according to WHO guideline (Figure 19) [30] .

PO_4-P content average value of the lake middle water in October, were 60.09 µg/L, 62.11 µg/L, 87.56 µg/L and 83.96 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the PO_4-P value at the cage and control site ($p=0.175$). November were54.41 µg/L, 57.83 µg/L,65.04 µg/L and 74.27 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the PO_4-P value at the cage and control site ($p=0.623$).

In December, the determined PO_4-P value was 585.04 µg/L, 625.40 µg/L, 205.40 µg/L and 215.09 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively.

No statistically significant difference existed between the PO_4-P value at the cage and control site (*p=239*) which is under the permissible limit of 14 mg/L according to WHO guideline (Figure 20) [30].

PO_4-P content average value of the lake bottom water in October, were 53.10 µg/L, 67.07 µg/L, 86.66 µg/L and 91.17 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the PO_4-P value at the cage and control site (*p=0.140*). In November, the determined PO_4-P value was 91.71µg/L, 55.49 µg/L, 54.23 µg/L and 78.10 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the PO_4-P value at the cage and control site (*p=0.523*). In December, the determined PO_4-P value was 444.32 µg/L, 525.04 µg/L, 148.66 µg/L and 178.37 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the PO_4-P value at the cage and control site (*p=0.318*) which is under the permissible limit of 14 mg/L according to WHO guideline (Figure 21) [30].

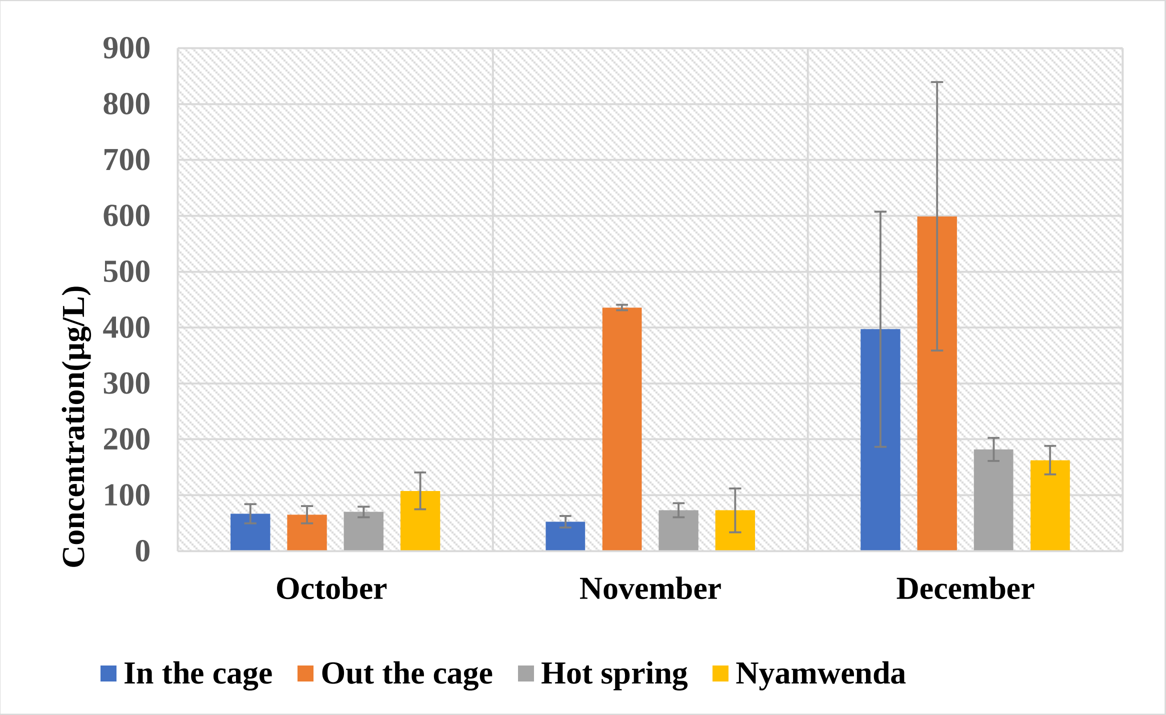

Figure 20: Concentration of Phosphate- Phosphorus (PO_4-P) in the surface water at Lake Kivu

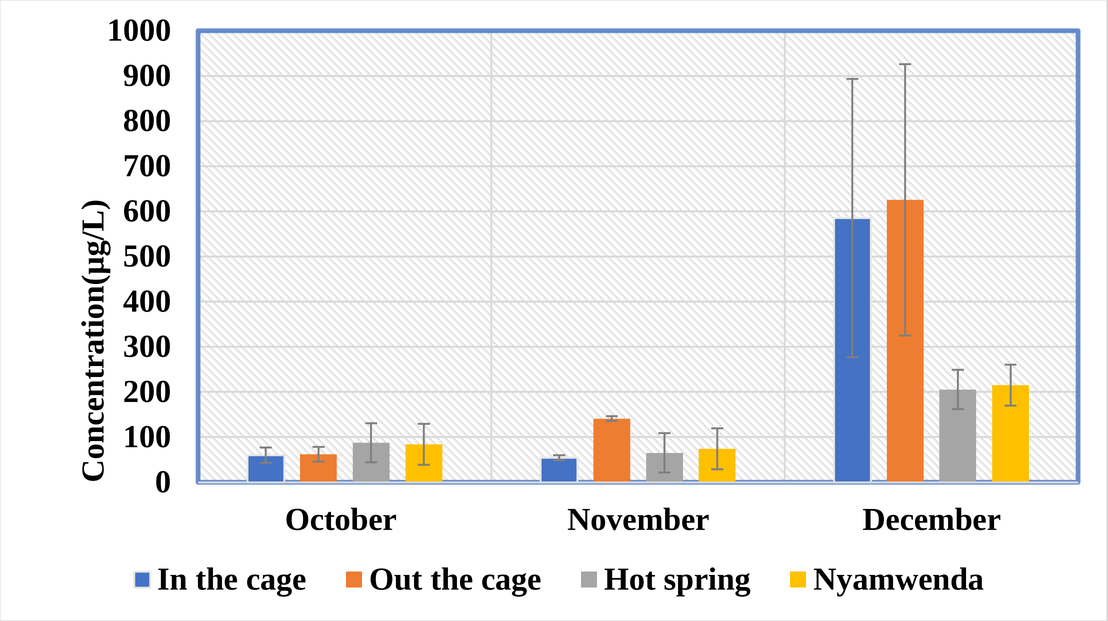

Figure 21: Concentration of Phosphate- Phosphorus (PO$_4$-P) in the middle water at Lake Kivu

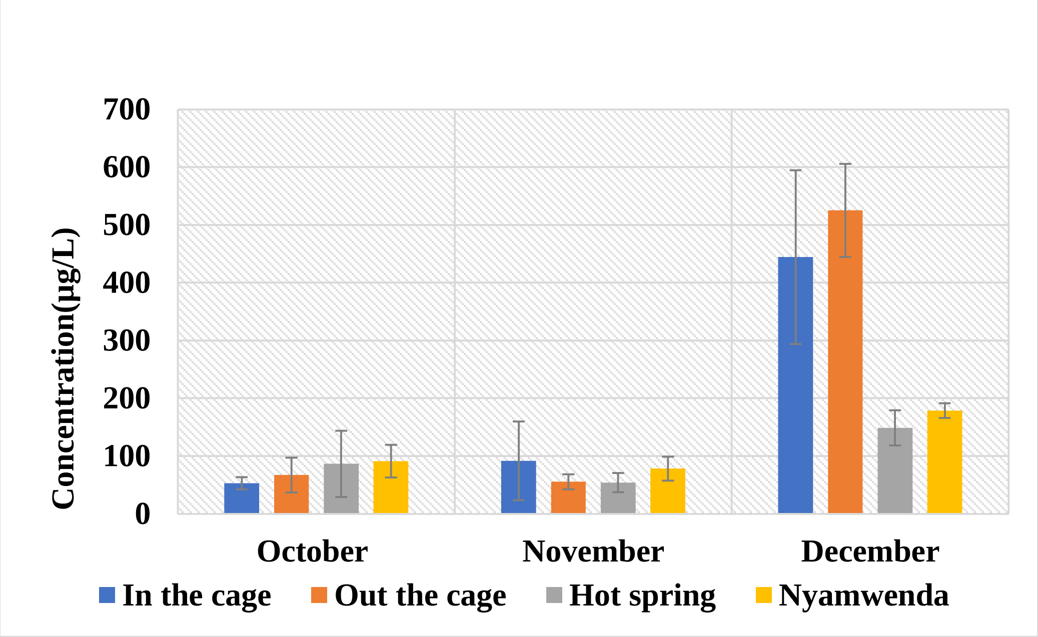

Figure 22: Concentration of Phosphate- Phosphorus (PO$_4$-P) in bottom water in Lake Kivu

Phosphate nutrients concentration between 0 – 12 mg/L show Oligotrophic Lake, 12 – 24 mg/L show mesotrophic lake, and 24 – 96 mg/L show Eutrophic [51].

According to Carlson assessment Trophic Status of Lakes guideline show that cage and control area were in Oligotrophic Lake means that water was clear and no contaminations of Phosphate-phosphorus. When referring to WHO standards for drinking water, the phosphate concentration is 2.5 mg/L.

4.5. Chlorophyll a

The concentration of chlorophyll a in water has a direct correlation with the amount of algae present. The concentration of chlorophyll a average value of the lake surface water in October, were 5.18 µg/L, 3.6 µg/L, 5.45 µg/L and 3.9 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the chlorophyll a value at the cage and control site (*p=0.763*). In November, the determined chlorophyll a value was 2.07 µg/L, 4.2 µg/L, 4.1µg/L and 3.3 µg/L from the cage, out of the cage, hot spring, and Nyamwenda respectively. No statistically significant difference existed between the chlorophyll a value at the cage and control site (p=*0.381*). December was 5.0 µg/L, 4.7 µg/L, 4.1 µg/L and 3.33 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively.

No statistically significant difference existed between the chlorophyll a value at the cage and control site (*p=0.753*) **(**Figure 22) [30].

Chlorophyll a content average value of the lake middle water in October, was 4.6 µg/L, 4.7 µg/L, 5.4 µg/L and 1.85 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the chlorophyll a value at the cage and control site (*p=0.186*). In November, the determined chlorophyll a value was 3.2 µg/L, 2.5 µg/L, 3.50 µg/L and 2.07 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the chlorophyll a value at the cage and control site (*p=0.399*). In December, the determined chlorophyll a value was 3.19 µg/L, 4.40 µg/L, 3.50 µg/L and 2.07 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively [30]. No statistically significant difference existed between the chlorophyll a value at the cage and control site (*p=0.312*) (Figure 23).

Chlorophyll a content average value of the lake bottom water in October, were 4.58 µg/L, 4.58 µg/L, 3.8 µg/L and 1.87 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively.

No statistically significant difference existed between the chlorophyll a value at the cage and control site (*p=0.082*). November was 3.45 µg/L, 2.48 µg/L, 4.58 µg/L and 2.36 µg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the chlorophyll a value at the cage and control site (*p=0.513*). In December, the determined chlorophyll a value was 3.11 µg/L, 2.10 µg/L, 4.58 µg/L and 2.36 µg/L from the cage, out of the cage, hot spring, and Nyamwenda respectively. No statistically significant difference existed between the chlorophyll a value at the cage and control site (*p=0.490*) (Figure 24) [52].

Chlorophyll a concentration in water is typically greatest in the sun seasons and lowest in the rain season as it is very difficult for plants to develop throughout the winter. Sewage lagoons may have algae blooms on them during the summer because there are lots of nutrients in the water and because the water can be warmer compared to other lakes.

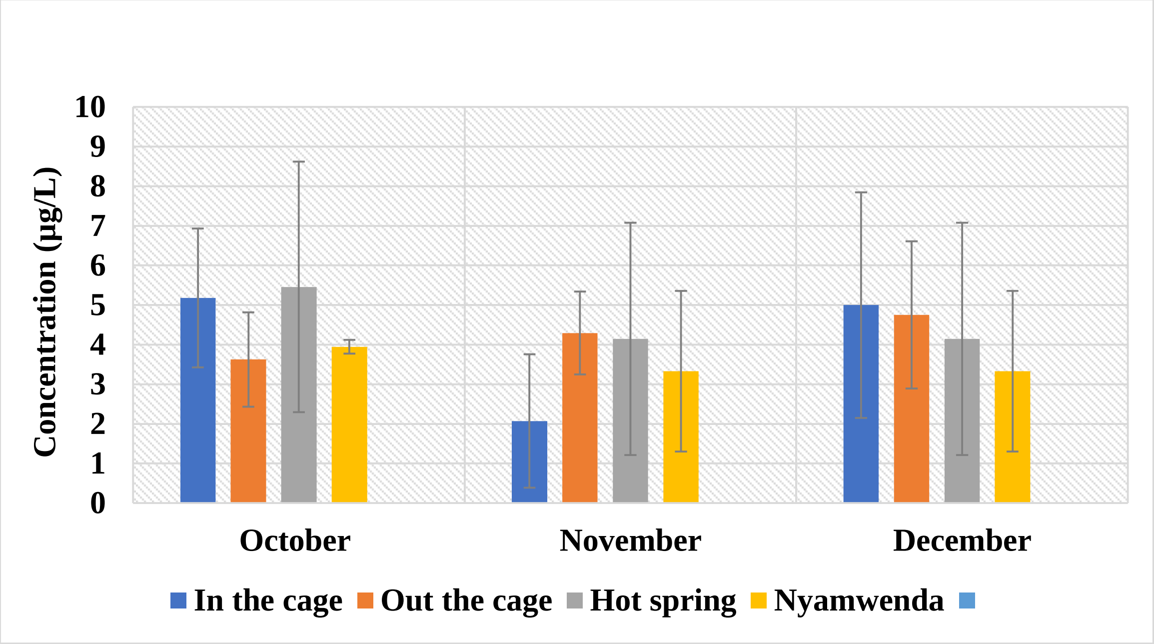

Figure 23: Concentration of chlorophyll a in Lake Kivu surface water

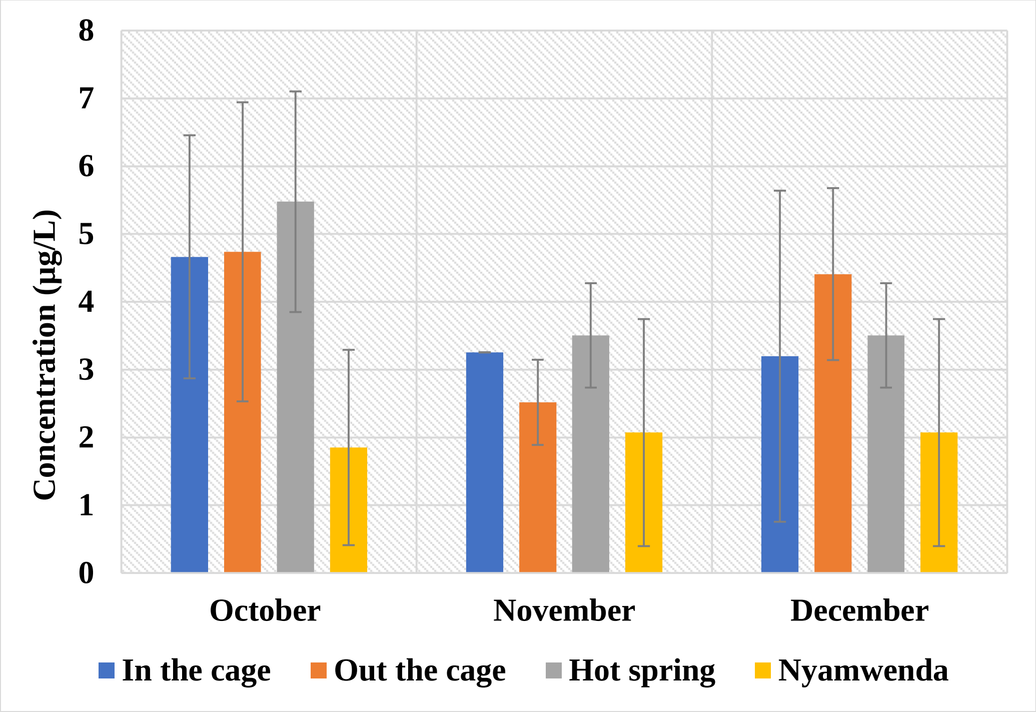

Figure 24: Concentration of chlorophyll a in Lake Kivu middle water

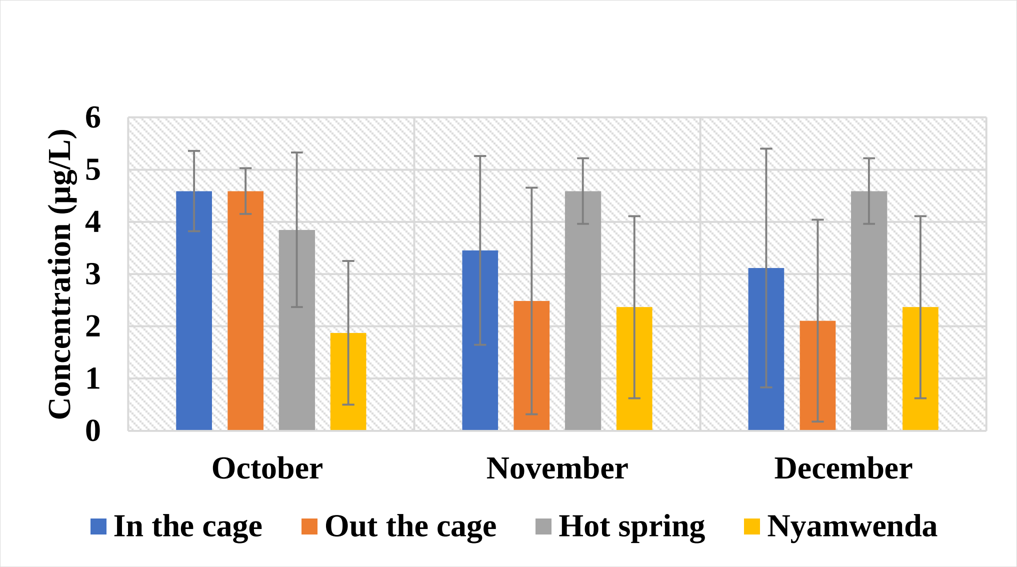

Figure 25: Concentration of chlorophyl a bottom water in Lake Kivu

The amount of chlorophyll a present in lake can be used to determine the lake's trophic status *[51]*. Chlorophyll a concentration Less than 8 µg/L means lake water is oligotrophic (clear water lower productivity), 8 to 25 µg/L mesotrophic (sometimes water are green means medium productivity), 26 to 75 µg/L eutrophic(high productivity more nutrients rich) and, over 75 µg/L hypereutrophic(extremely high productivity because there are frequent dense algal blooms) *[53]*. According to the results obtained from the lake in the cage and control site show that is oligotrophic (low productivity) because the concentration of chlorophyll less than 8 µg/L *[54]*.

4.6. Total Suspended Solid (TSS)

TSS content average value of the lake surface water in October, were 5.86 mg/L, 6.25 mg/L, 3.75 mg/L and 7.80 mg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the TSS value at the cage and control site (*p=0.197*). In November, the determined TSS value was 3.96 mg/L, 2.52 mg/L, 3.32 mg/L and 4.21 mg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the TSS value at the cage and control site (*p=0.614*). December was 3.41 mg/L, 2.85 mg/L, 1.56 mg/L and 3.25 mg/L from the cage, out of the cage, hot spring, and Nyamwenda respectively.

No statistically significant difference existed between the TSS value at the cage and control site (*p=0.276*) which is under the permissible limit of 25 mg/L according to WHO guideline (Figure 25) [30] .

TSS content average value of the lake middle water in October, was 5 mg/L, 4.64 mg/L, 6.66 mg/L and 11.37 mg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. The difference in TSS value between the cage and the control site was statistically significant (*p=0.008*). In November the determined TSS value was 3.21 mg/L, 2.18 mg/L, 1.39 mg/L and 7.23 mg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the TSS value at the cage and control site (*p=0.138*). December was 4.95 mg/L, 2.17 mg/L, 2.36 mg/L and 2.40 mg/L from the cage, out of the cage, hot spring, and Nyamwenda respectively. No statistically significant difference existed between the TSS value at the cage and control site (*p=0.507*) which is under the permissible limit of 25 mg/L according to WHO guideline (Figure 26) [30].

TSS content average value of the lake bottom water in October, was 7.55 mg/L, 3.80 mg/L, 3.80 mg/L and 12.02 mg/L from the cage, out of the cage, hot spring, and Nyamwenda respectively. No statistically significant difference existed between the TSS value at the cage and control site (*p=0.140*). November was 4.20 mg/L, 2.46 mg/L, 1.48 mg/L and 8.90 mg/L from the cage, out of the cage, hot spring, and Nyamwenda respectively.

No statistically significant difference existed between the TSS value at the cage and control site (*p=0.008*). In December, the determined TSS value was 4.95 mg/L, 1.46 mg/L, 1.11 mg/L and 4.13 mg/L from the cage, out of the cage, hot spring, and Nyamwenda, respectively. No statistically significant difference existed between the TSS value at the cage and control site (*p=0.076*) which is under the permissible limit of 25 mg/L according to WHO guideline (Figure 27) [30].

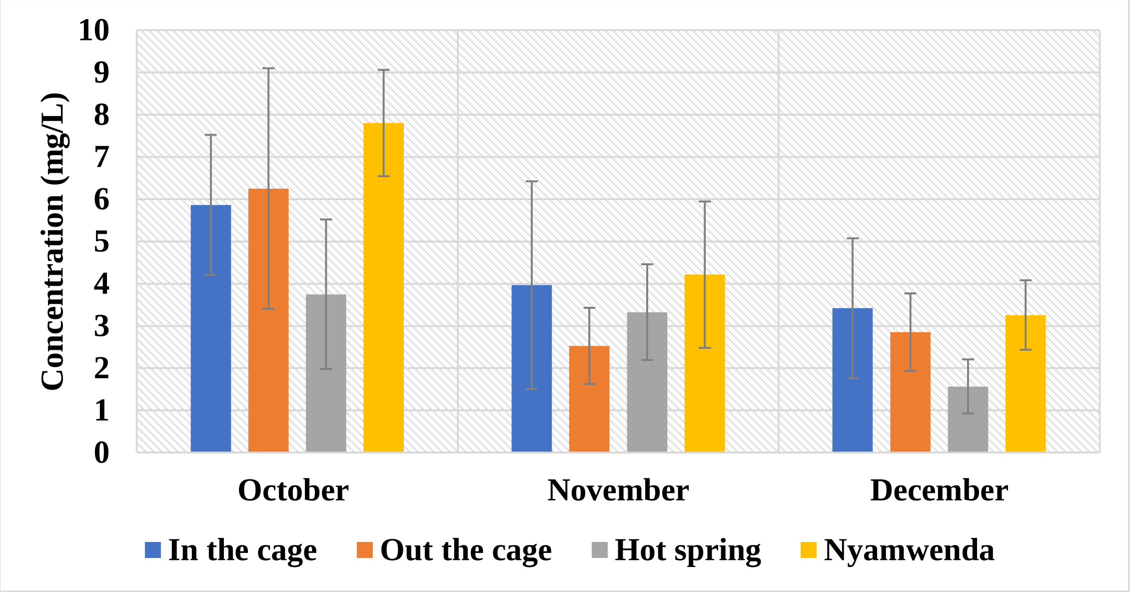

Figure 26: Concentration of Total Suspended Solids (TSS) surface water in Lake Kivu

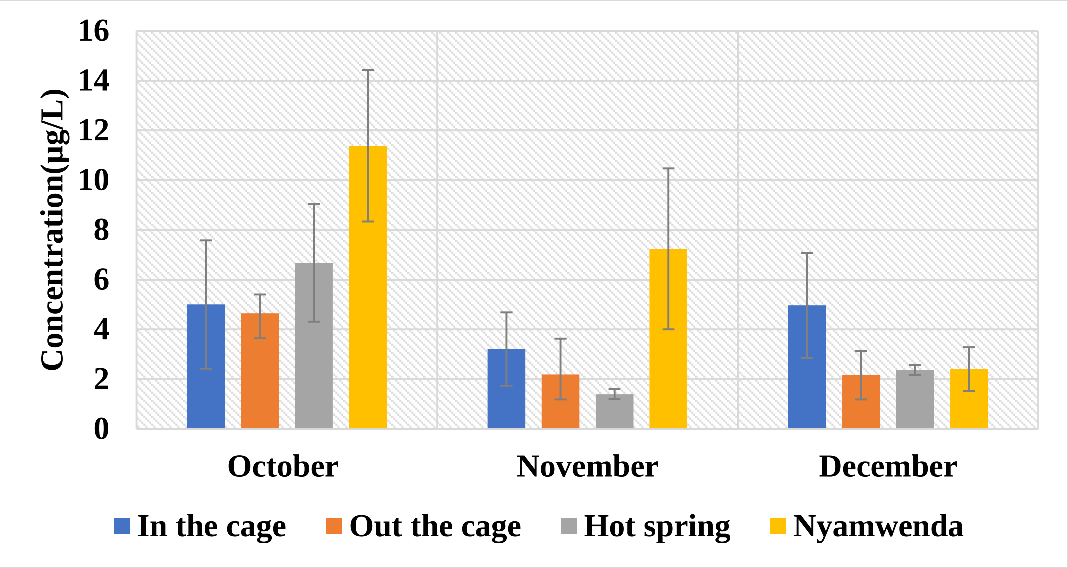

Figure 27: Concentration of Total Suspended Solids (TSS) middle water in Lake Kivu

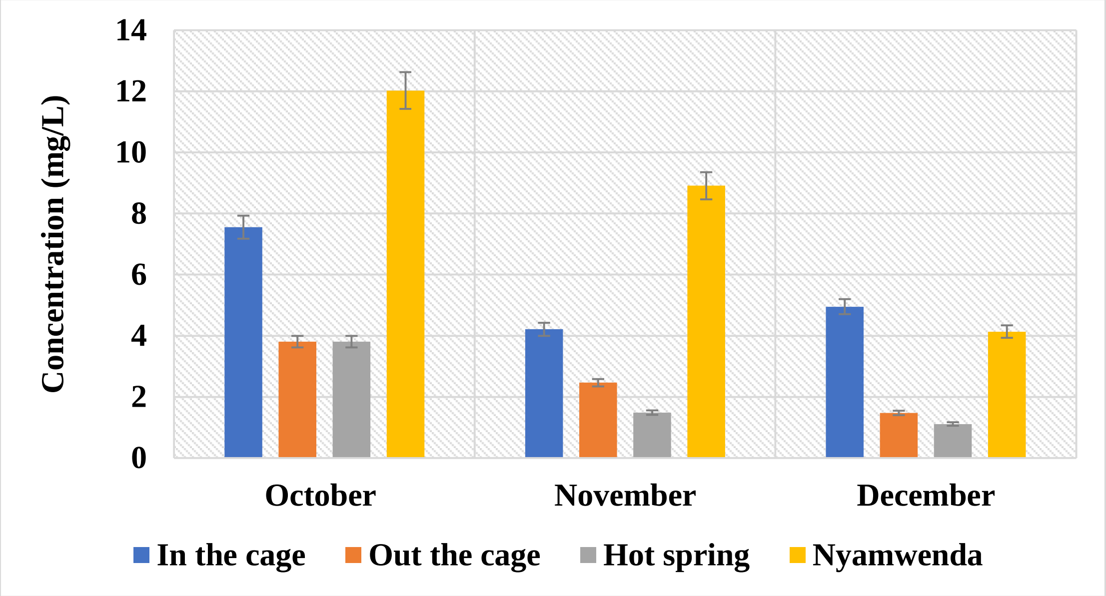

Figure 28: Concentration of Total Suspended Solids (TSS) bottom water in Lake Kivu

4.7. Secchi disk

Secchi disk measures the transparency on the depth at which the white and black Secchi disk is observable in the lake. Algae and suspended particulate matter were the two main factors that influenced the clarity of the water.

Soil dead leaves might be brought into the water by one or the other overflow or residue currently on the lower part of the lake. Fragmentation from building, horticultural lands, fish waste, and lakeside all lead to expanded overflow [55].

Secchi disk means depth value of the lake water in October, was 2.23 m, 2.39 m, 2.69 m and 1.33 m from the cage, out of the cage, hot spring, and Nyamwenda, respectively. The difference in Secchi disk values between the cage and the control site was statistically significant ($p=0.006$). In November, the determined Secchi disk depth value was 2.605 m, 2.895 m, 3.7 m, and 1.57 m from the cage, out of the cage, hot spring, and Nyamwenda respectively. The difference in Secchi disk values between the cage and the control site was statistically significant ($p=0.4.66*10^{-5}$). In December, the determined Secchi disk depth value was 2.28 m, 2.98 m, 3.3 m, and 1.98 m from the cage, out of the cage, hot spring, and Nyamwenda, respectively. The difference in Secchi disk values between the cage and the control site was statistically significant ($p=0.0002$) (Figure 28)

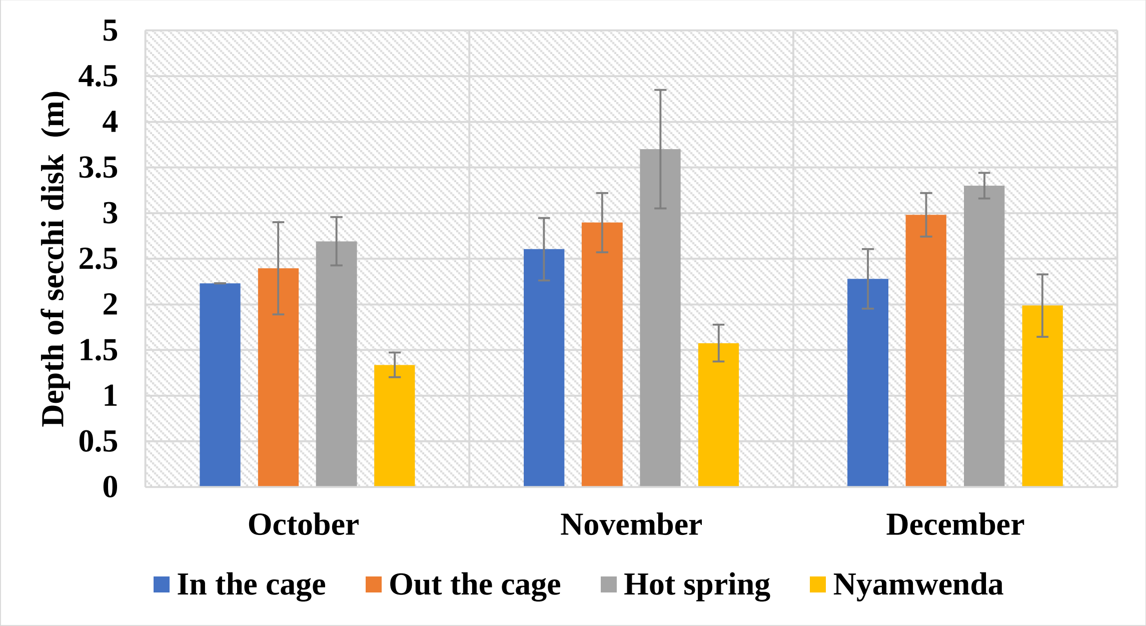

Figure 29: Depth of Secchi disk in (m) at Lake Kivu

Secchi disk seen in Secchi Depth > 4 m Oligotrophic, Mesotrophic range from (4 – 2 m), Eutrophic range from (2 - 0.5 m), Hypereutrophic range from (0.5 - < 0.25) [51]. According to the results obtained in this show that mesotrophic mean that the lake Kivu has less clear water [52].

4.8. Sediment analysis

4.8.1. Organic matter

Different synthetic mixtures develop in marine silt from the seawater segment.

This may result in a higher-than-normal concentration of organic carbon and phosphate in the sediment (seabed). The outcomes of the analysis of the sediment's organic matter content at each sampling site can be recorded and represented below.

In October, total organic matter the lake value from the cage, outside the cage, hot spring, and Nyamwenda, was 7.72%, 5.89%, 5.98%, and 7.23% respectively. ANOVA, *p=0.214*, revealed that concentrations TOM were insignificantly distinct from the ones at the reference location and caged area.

The total organic matter value of the lake water in November, was 7.57%, 5.51%, 5.1% and 6.58% from the cage, out of the cage, hot spring, and Nyamwenda, respectively. ANOVA, p=0.235, revealed that TOM concentrations did not significantly differ from those at the reference site (Figure 29).

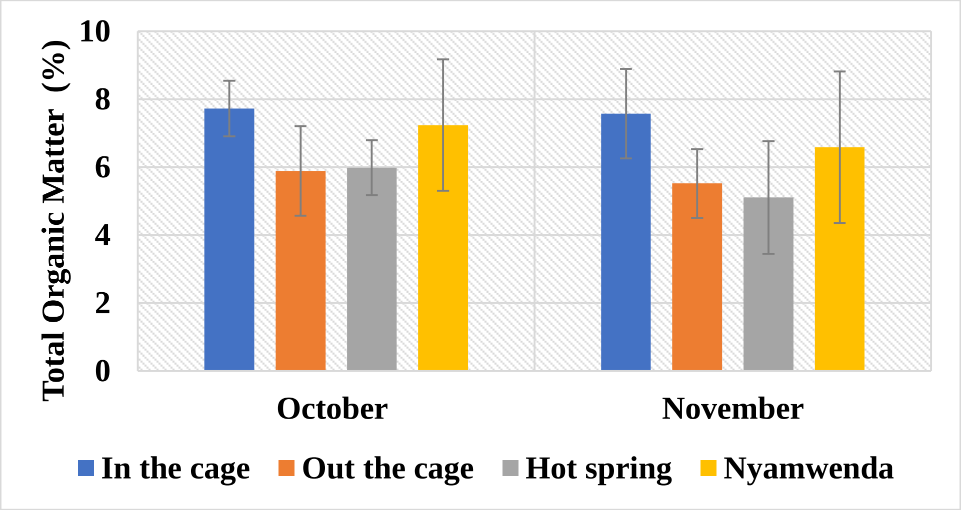

Figure 30: % of Total Organic Matter (TOM) in the sediment

Sediment contamination can be estimated using the TOM content of the sediment. For a zone to be considered uncontaminated, the sediment's organic matter level should range from 0 to 5 percent, whereas in contaminated zones, sediments typically contain more than 15 percent organic matter. The samples examined had TOM between 5.1%–7.72% [27, 56].

According to Reynolds classification, there are five categories of sediment organic matter content: Very high organic matter content > 35%, high organic matter ranges from 17-35%, medium organic matter content ranges from 7-17%, and poor organic matter content ranges from 3.5-7% [46]. According to Hartoko, Sandstone sediments contain a low level of organic matter. This is because sand sediment has greater pores that allows water for good oxidation. Contrarily, the silt with a finer texture contains more organic matter stuff. The total organic matter in the water from Lake Kivu is still within the permissible range for excellent quality standards and is still below the limit [57]. Due to the organic matter concentration, the examined locations' sediments ranged from being mildly polluted to being uncontaminated, based on the results of the research area's organic matter. Alpaslan noted the presence of organic debris in the cage-station sediments of the Kesikköprü Reservoir in Turkey values ranging from 13.12% to 15.57%. An oligotrophic Passage Lake in Canada's rainbow trout cage culture had an organic matter level of 39% to 69% [48].

CHAPTER 5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

As the cage fish farming output rises to meet the growing demand for seafood, For the protection and management of an aquatic system, it is essential to have knowledge of the environmental effects of cage culture. According to the findings values (nitrate-nitrogen, ammonium-nitrogen, chlorophyll a, phosphate-phosphorus, chlorophyll a, total suspended solid, and organic matter) of the study from the farm were not substantially different from those of the reference location. The ammonium-Nitrogen values between control site and cage fish farming were no different and was in acceptable range [58]. The nitrogen value found was under the permissible limit of 50 mg/L according to WHO guideline. Phosphate nutrients concentration found between 0 – 12 mg/L show that Oligotrophic according to Carlson assessment Trophic Status of Lakes. According to the results of chlorophyll a that determine the lake's trophic status showed the lake is oligotrophic (clear water lower productivity). Secchi disk results were between 3.7 and 1.33 m indicator the lake has less clear water. The sediment organic matter was less than 15 % as the samples examined had TOM between 5.1%–7.72% means that was in acceptable limit. The fish cage facility did not cause any disturbances or have any effect on certain physical and chemical parameters of the water body or sediment. Therefore, momentum endeavors to advance business confine fish culture undertakings in Lake Kivu and other water bodies ought to tread carefully, particularly regarding site area and enclosure focus at any one site. In fact, there is no evidence that caged fish farming affects water quality [59].

5.2. Recommendations

The following is suggested with respect to the results obtained:

- To evaluate the effects on nutrient loading, cage culture operators will be required frequently gather information on the trophic status in and around the enclosures as well as in regions from the enclosures. In accordance with risk awareness, additional research on the physical and chemical characteristics of sediments and water will be carried out.
- For authorities to evaluate the effects on nutrient loading, operators of cage cultures are required regularly gather information on the trophic status both in and around the cages and far away, as well as report this information.

- According to the awareness of the risks, it is also necessary to perform more research on other physical and chemical properties of the water and sediments such as COD, BOD, P^H, total hardness, dissolved oxygen, total organic carbon, total nitrogen, temperature, and total phosphorus.
- It's important to take the rise in nutrients away from the caged area as a warning.
- When approving cage culture in the lake, caution should be used to prevent further degradation of the water quality and impairment of the lake's capacity to sustainably benefit the communities whose livelihoods depend on it.
- When thinking about the development of fish processing facilities, careful site selection and ongoing environmental monitoring are required.
- In the confirmation of the choice of cage fish farming, consistent ecological be a fundamental part while thinking about construction of fish cage in Lake Kivu.

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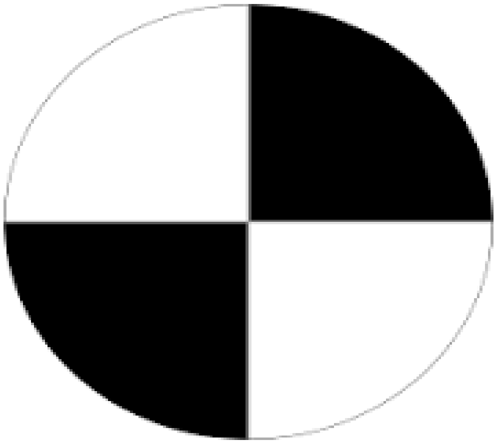
Appendix

Material used in sampling.

1. **Niskin bottled water sampler.**

2. **Echo sounder and Secchi disk**



3. Ekman grab sampler for sediment collection

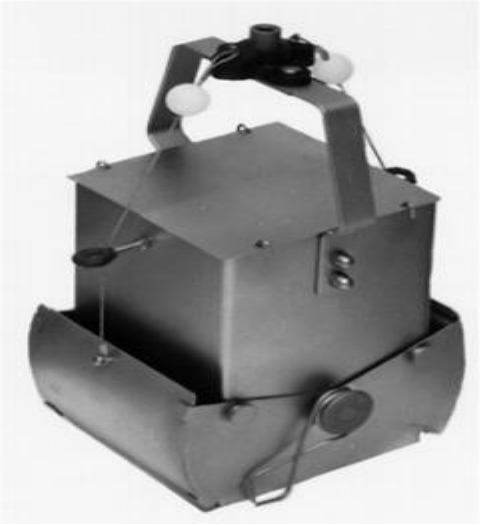


Table 1. One way ANOVA depth surface water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	20	5	0
Out of the cage	4	20	5	0
Hot spring	2	8	4	2
Nyamwenda	4	18	4.5	1

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.857143	3	0.619048	1.238095	0.346799	3.708265
Within Groups	5	10	0.5			
Total	6.857143	13				

Table 2. One way ANOVA depth of middle water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	49	12.25	4.25
Out of the cage	4	62	15.5	11
Hot spring	3	26	8.666667	36.33333
Nyamwenda	4	38	9.5	17.66667

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	105.9167	3	35.30556	2.265597	0.137766	3.587434
Within Groups	171.4167	11	15.58333			
Total	277.3333	14				

Table 3. One way ANOVA depth of bottom water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	79	19.75	14.91667
Out of the cage	4	95	23.75	25.58333
Hot spring	2	26	13	98
Nyamwenda	4	58	14.5	30.33333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	240.92857	3	80.30952	2.586458	0.111345	3.708265
Within Groups	310.5	10	31.05			
Total	551.42857	13				

Table 4. One way ANOVA depth of surface water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	17	3.4	0.8
Out of the cage	5	15	3	0
Hot spring	3	8	2.666667	0.333333
Nyamwenda	4	11	2.75	0.25

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.383333	3	0.461111	1.298436	0.316728	3.410534
Within Groups	4.616667	13	0.355128			
Total	6	16				

Table 5. One way ANOVA depth of middle water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	55	13.75	14.91667
Out of the cage	4	59	14.75	24.91667
Hot spring	2	10	5	0
Nyamwenda	4	44	11	25.33333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	144.5	3	48.16667	2.463768	0.122449	3.708265
Within Groups	195.5	10	19.55			
Total	340	13				

Table 6. One way ANOVA depth of bottom water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	115	23	32.5
Out of the cage	5	130	26	42.5
Hot spring	2	25	12.5	12.5
Nyamwenda	4	67	16.75	27.5833333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	361.6875	3	120.5625	3.66034156	0.04411276	3.4902948
Within Groups	395.25	12	32.9375			
Total	756.9375	15				

Table 7. One way ANOVA depth of surface water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	15	3	0
Out of the cage	5	15	3	0
Hot spring	2	4	2	2
Nyamwenda	4	10	2.5	1

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2	3	0.666667	1.6	0.241102	3.490295
Within Groups	5	12	0.416667			
Total	7	15				

Table 8. One way ANOVA depth of middle water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	80	16	84
Out of the cage	5	114	22.8	52.7
Hot spring	2	12	6	18
Nyamwenda	4	30	7.5	5.6666667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	695.2	3	231.733333	4.7796494	0.020455	3.490295
Within Groups	581.8	12	48.4833333			
Total	1277	15				

Table 9. One way ANOVA depth of bottom water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	122	24.4	22.3
Out of the cage	5	136	27.2	39.2
Hot spring	2	21	10.5	60.5
Nyamwenda	4	63	15.75	22.91666667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	578.5	3	192.8333333	6.16655563	0.008850529	3.490295
Within Groups	375.25	12	31.27083333			
Total	953.75	15				

Table 10. One way ANOVA Ammonium-Nitrogen surface water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	38.89618922	9.724047306	34.91882046
Out of the cage	4	56.41699518	14.1042488	113.198374
Hot spring	2	4.336399474	2.168199737	1.942599215
Nyamwenda	4	50.2847131	12.57117827	142.9369299

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	209.7527498	3	69.91758327	0.798962244	0.522194259	3.708264819
Within Groups	875.1049723	10	87.51049723			
Total	1084.857722	13				

Table 11. One way ANOVA Ammonium-Nitrogen middle water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	25.75558476	6.438896189	26.79667724
Out of the cage	4	39.77222952	9.943057381	39.45954619
Hot spring	2	10.24967148	5.124835742	21.58443572
Nyamwenda	4	45.46649146	11.36662286	94.95552871

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	80.61615437	3	26.87205146	0.531888441	0.670632387	3.70826481
Within Groups	505.2196921	10	50.52196921			
Total	585.8358465	13				

Table 12. One way ANOVA Ammonium-Nitrogen bottom water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	12.17696014	3.044240035	11.68757223
Out of the cage	4	68.68155935	17.17038984	67.5353011
Hot spring	2	12.00175208	6.00087604	42.30549402
Nyamwenda	4	51.59877354	12.89969339	165.0489852

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	463.3870001	3	154.4623334	1.992751061	0.17908556	3.708264819
Within Groups	775.1210695	10	77.51210695			
Total	1238.50807	13				

Table 13. One way ANOVA Ammonium-Nitrogen surface water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	44.02102	8.804205	31.23508
Out of the cage	5	105.6505	21.13009	980.3915
Hot spring	2	18.39685	9.198423	6.139573
Nyamwenda	4	44.02102	11.00526	3.977132

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	462.2903	3	154.0968	0.454945	0.718658	3.490295
Within Groups	4064.577	12	338.7148			
Total	4526.868	15				

Table 14. One way ANOVA Ammonium-Nitrogen middle water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	84.53789	16.90758	338.0219
Out of the cage	5	122.2952	24.45905	632.3814
Hot spring	2	16.64477	8.322383	0.383723
Nyamwenda	4	26.71923	6.679807	32.66445

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	825.1467	3	275.0489	0.829295	0.502922	3.490295
Within Groups	3979.99	12	331.6658			
Total	4805.137	15				

Table 15. One way ANOVA Ammonium-Nitrogen bottom water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	99.08016	19.81603	160.4708
Out of the cage	5	71.8353	14.36706	74.09697
Hot spring	3	19.05388	6.351292	0.047965
Nyamwenda	4	28.47131	7.117827	0.94332

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	512.2662	3	170.7554	2.358508	0.119041	3.410534
Within Groups	941.1969	13	72.39976			
Total	1453.463	16				

Table 16. One way ANOVA Ammonium-Nitrogen surface water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	291.4533	58.29067	736.2953
Out of the cage	5	247.2539	49.45079	924.5105
Hot spring	2	30.63323	15.31662	55.15464
Nyamwenda	4	91.46208	22.86552	100.1433

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4485.183	3	1495.061	2.563398	0.103545	3.490295
Within Groups	6998.808	12	583.234			
Total	11483.99	15				

Table 17. One way ANOVA Ammonium-Nitrogen middle water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	241.1273	48.22546	646.0945
Out of the cage	5	240.6897	48.13794	217.1714
Hot spring	2	3.938558	1.969279	7.756121
Nyamwenda	4	42.01129	10.50282	22.34274

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6255.159	3	2085.053	7.092322	0.005358	3.490295
Within Groups	3527.848	12	293.9873			
Total	9783.007	15				

Table 18. One way ANOVA Ammonium-Nitrogen bottom water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	232.156142	46.4312284	402.41822
Out of the cage	5	177.235132	35.4470264	575.58082
Hot spring	2	41.5736729	20.7868365	510.27619
Nyamwenda	4	184.674631	46.1686578	72.071285

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1199.763671	3	399.921224	1.0346166	0.412185	3.490295
Within Groups	4638.486211	12	386.540518			
Total	5838.249881	15				

Table 19. One way ANOVA Nitrate – Nitrogen (NO_3-N) Surface water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	236.849	59.21224	497.4295
Out of the cage	4	460.1563	115.0391	8159.637
Hot spring	2	396.7448	198.3724	37562.26
Nyamwenda	4	1081.25	270.3125	30189.51

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	100037.1	3	33345.71	2.163872	0.155539	3.708265
Within Groups	154102	10	15410.2			
Total	254139.1	13				

Table 20. One way ANOVA Nitrate – Nitrogen (NO_3-N) middle water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	206.25	51.5625	516.2557
Out of the cage	4	668.4896	167.1224	9816.064
Hot spring	2	371.3542	185.6771	12617.32
Nyamwenda	4	986.849	246.7122	25046.56

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	78628.8	3	26209.6	2.20705	0.150182	3.708265
Within Groups	118754	10	11875.4			
Total	197382.8	13				

Table 21. One way ANOVA Nitrate – Nitrogen (NO_3-N) bottom water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	339.7135	84.92839	1360.681
Out of the cage	4	969.9219	242.4805	13764.38
Hot spring	2	333.5938	166.7969	2754.211
Nyamwenda	4	1448.438	362.1094	176780.7

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	161430.6	3	53810.19	0.930213	0.461543	3.708265
Within Groups	578471.5	10	57847.15			
Total	739902.1	13				

Table 22. One way ANOVA Nitrate – Nitrogen (NO_3-N) surface water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	242.1875	48.4375	2137.375
Out of the cage	5	782.5521	156.5104	75555.25
Hot spring	3	31.64063	10.54688	11.44409
Nyamwenda	4	61.71875	15.42969	75.02238

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	61956.56	3	20652.19	0.863223	0.48472	3.410534
Within Groups	311018.5	13	23924.5			
Total	372975	16				

Table 23. One way ANOVA Nitrate – Nitrogen (NO_3-N) middle water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	206.3802	41.27604	2248.849
Out of the cage	5	867.8385	173.5677	124093.5
Hot spring	2	5.46875	2.734375	7.629395
Nyamwenda	4	71.48438	17.87109	222.2061

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	77614.97	3	25871.66	0.613504	0.6192	3.490295
Within Groups	506043.6	12	42170.3			
Total	583658.6	15				

Table 24. One way ANOVA Nitrate – Nitrogen (NO_3-N) bottom water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	877.6042	175.5208	52699.11
Out of the cage	5	281.25	56.25	1408.768
Hot spring	2	39.97396	19.98698	10.38445
Nyamwenda	4	77.34375	19.33594	80.39121

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	70364.18	3	23454.73	1.298933	0.319833	3.490295
Within Groups	216683.1	12	18056.92			
Total	287047.3	15				

Table 25. One way ANOVA Nitrate – Nitrogen (NO_3-N) surface water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	412	82.4	3203.689
Out of the cage	5	424	84.8	702.7556
Hot spring	2	277.3333	138.6667	512
Nyamwenda	4	545.3333	136.3333	191.2593

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10759.56	3	3586.519	2.575357	0.102524	3.490295
Within Groups	16711.56	12	1392.63			
Total	27471.11	15				

Table 26. One way ANOVA Nitrate – Nitrogen (NO_3-N) middle water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	394	78.8	2575.2
Out of the cage	5	461.3333	92.26667	2364.8
Hot spring	2	300.6667	150.3333	826.8889
Nyamwenda	4	554.6667	138.6667	257.1852

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12828.11	3	4276.037	2.402443	0.118478	3.490295
Within Groups	21358.44	12	1779.87			
Total	34186.56	15				

Table 27. One way ANOVA Nitrate – Nitrogen (NO_3-N) bottom water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	510	102	3294.222
Out of the cage	5	700	140	809.7778
Hot spring	2	297.3333	148.6667	2134.222
Nyamwenda	4	184.6746	46.16866	72.07129

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	23819.05	3	7939.684	5.076947	0.016927	3.490295
Within Groups	18766.44	12	1563.87			
Total	42585.49	15				

Table 28. One way ANOVA Phosphate- Phosphorus (PO4-P) surface water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	267.3874	66.84685	299.7592
Out of the cage	4	260.1802	65.04505	243.4867
Hot spring	2	140	70	91.30752
Nyamwenda	4	430.4505	107.6126	1082.366

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4801.935	3	1600.645	3.221817	0.069741	3.708265
Within Groups	4968.144	10	496.8144			
Total	9770.079	13				

Table 29. One way ANOVA Phosphate- Phosphorus (PO4-P) middle water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	240.3604	60.09009	286.5027
Out of the cage	4	248.4685	62.11712	265.3329
Hot spring	2	175.1351	87.56757	1460.92
Nyamwenda	4	335.8559	83.96396	67.6352

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2010.534	3	670.1779	2.019014	0.175215	3.708265
Within Groups	3319.333	10	331.9333			
Total	5329.867	13				

Table 30. One way ANOVA Phosphate- Phosphorus (PO4-P) bottom water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	212.4324	53.10811	109.5014
Out of the cage	4	268.2883	67.07207	897.8573
Hot spring	2	173.3333	86.66667	3287.071
Nyamwenda	4	364.6847	91.17117	800.2597

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3416.872	3	1138.957	1.307655	0.325471	3.708265
Within Groups	8709.926	10	870.9926			
Total	12126.8	13				

Table 31. One way ANOVA Phosphate- Phosphorus (PO4-P) surface water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	263.0631	52.61261	106.8907
Out of the cage	5	2179.279	435.8559	726474.1
Hot spring	3	219.4595	73.15315	159.078
Nyamwenda	4	291.7117	72.92793	1530.382

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	487888.3	3	162629.4	0.726215	0.554282	3.410534
Within Groups	2911233	13	223941			
Total	3399122	16				

Table 32. One way ANOVA Phosphate- Phosphorus (PO4-P) middle water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	272.0721	54.41441	33.43884
Out of the cage	5	705.4054	141.0811	34667.48
Hot spring	2	130.0901	65.04505	1014.528
Nyamwenda	4	297.1171	74.27928	694.4106

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	21534.17	3	7178.056	0.607018	0.623042	3.490295
Within Groups	141901.4	12	11825.12			
Total	163435.6	15				

Table 33. One way ANOVA Phosphate- Phosphorus (PO4-P) bottom water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	458.5586	91.71171	4626.086
Out of the cage	5	277.4775	55.4955	172.7133
Hot spring	2	108.4685	54.23423	274.3284
Nyamwenda	4	312.4324	78.10811	422.8553

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4083.709	3	1361.236	0.787673	0.523618	3.490295
Within Groups	20738.09	12	1728.174			
Total	24821.8	15				

Table 34. One way ANOVA Phosphate- Phosphorus (PO4-P) surface water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	1985.586	397.1171	135710.7
Out of the cage	5	2994.595	598.9189	190789.1
Hot spring	2	363.964	181.982	415.5507
Nyamwenda	4	650.4505	162.6126	654.4382

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	508087.9	3	169362.6	1.553337	0.251764	3.490295
Within Groups	1308378	12	109031.5			
Total	1816466	15				

Table 35. One way ANOVA Phosphate- Phosphorus (PO4-P) middle water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	2925.225	585.045	201087.8
Out of the cage	5	3127.027	625.4054	157890.3
Hot spring	2	410.8108	205.4054	934.989
Nyamwenda	4	860.3604	215.0901	5625.829

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	584452.7	3	194817.6	1.608152	0.239291	3.490295
Within Groups	1453725	12	121143.8			
Total	2038178	15				

Table 36. One way ANOVA Phosphate- Phosphorus (PO4-P) bottom water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	2221.622	444.3243	109381.3
Out of the cage	5	2625.225	525.045	190695.3
Hot spring	2	297.3333	148.6667	2134.222
Nyamwenda	4	713.5135	178.3784	162.8656

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	392425	3	130808.3	1.304898	0.318024	3.490295
Within Groups	1202929	12	100244.1			
Total	1595354	15				

Table 37. One way ANOVA Total Suspended Solid (TSS) surface water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	23.45455	5.863636	2.741047
Out of the cage	4	25	6.25	8.101852
Hot spring	2	7.5	3.75	3.125
Nyamwenda	4	31.22222	7.805556	1.583333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	22.76866	3	7.589552	1.87843	0.197134	3.708265
Within Groups	40.4037	10	4.04037			
Total	63.17235	13				

Table 38. One way ANOVA Total Suspended Solid (TSS) middle water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	20	5	6.666667
Out of the cage	4	18.56275	4.640688	0.58665
Hot spring	2	13.33333	6.666667	5.555556
Nyamwenda	4	45.5	11.375	9.229167

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	115.0241	3	38.34136	6.970775	0.008193	3.708265
Within Groups	55.00301	10	5.500301			
Total	170.0271	13				

Table 39. One way ANOVA Total Suspended Solid (TSS) bottom water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	30.22222	7.555556	24.19753
Out of the cage	3	11.42857	3.809524	5.251701
Hot spring	2	7.619048	3.809524	0.453515
Nyamwenda	4	48.10606	12.02652	36.12402

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	150.0666	3	50.0222	2.345749	0.140951	3.862548
Within Groups	191.9216	9	21.32462			
Total	341.9882	12				

Table 40. One way ANOVA Total Suspended Solid (TSS) surface water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	21.61905	4.32381	6.056009
Out of the cage	4	10.95238	2.738095	0.812547
Hot spring	3	9.972527	3.324176	1.282303
Nyamwenda	4	13.27273	3.318182	3.00551

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5.93818	3	1.979393	0.621103	0.614724	3.490295
Within Groups	38.24281	12	3.186901			
Total	44.18099	15				

Table 41. One way ANOVA Total Suspended Solid (TSS) middle water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	16.06494	3.212987	2.161882
Out of the cage	5	10.91841	2.183683	2.081554
Hot spring	2	2.788462	1.394231	0.041605
Nyamwenda	4	28.92803	7.232008	38.31127

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	73.19981	3	24.39994	2.219031	0.138574	3.490295
Within Groups	131.9492	12	10.99576			
Total	205.149	15				

Table 42. One way ANOVA Total Suspended Solid (TSS) bottom water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	21.04906	4.209812	7.640982
Out of the cage	5	12.31283	2.462567	3.102762
Hot spring	2	2.967033	1.483516	0.006038
Nyamwenda	4	35.63743	8.909357	10.91786

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	117.1447	3	39.04823	6.187118	0.008748	3.490295
Within Groups	75.73458	12	6.311215			
Total	192.8793	15				

Table 43. One way ANOVA Total Suspended Solid (TSS) surface water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	17.08791	3.417582	2.747521
Out of the cage	5	12.61905	2.52381	0.839002
Hot spring	2	3.131313	1.565657	0.413223
Nyamwenda	4	13.02718	3.256796	0.680631

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6.099353	3	2.033118	1.452123	0.276728	3.490295
Within Groups	16.80121	12	1.400101			
Total	22.90056	15				

Table 44. One way ANOVA Total Suspended Solid (TSS) middle water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	19.83883	4.959707	22.74154
Out of the cage	4	8.711844	2.177961	0.88967
Hot spring	2	4.722222	2.361111	0.03858
Nyamwenda	4	9.626631	2.406658	3.49489

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	20.23158	3	6.74386	0.828312	0.507957	3.708265
Within Groups	81.41687	10	8.141687			
Total	101.6485	13				

Table 45. One way ANOVA Total Suspended Solid (TSS) bottom water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	24.7619	4.952381	10.63039
Out of the cage	4	5.877345	1.469336	0.175684
Hot spring	2	2.222222	1.111111	2.469136
Nyamwenda	4	16.53788	4.13447	0.850106

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	39.42429	3	13.14143	3.007314	0.076426	3.587434
Within Groups	48.06805	11	4.369823			
Total	87.49234	14				

Table 46. One way ANOVA Secchi disk Lake Kivu water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	8.66	2.165	0.452367
Out of the cage	4	9.58	2.395	0.2547
Hot spring	4	10.765	2.69125	0.069723
Nyamwenda	4	5.345	1.33625	0.012223

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.061406	3	1.353802	6.863273	0.006043	3.490295
Within Groups	2.367038	12	0.197253			
Total	6.428444	15				

Table 47. One way ANOVA Secchi disk Lake Kivu water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	13.025	2.605	0.117
Out of the cage	5	14.475	2.895	0.106375
Hot spring	3	11.1	3.7	0.4225
Nyamwenda	4	6.3	1.575	0.040417

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8.238926	3	2.746309	19.19721	4.66E-05	3.410534
Within Groups	1.85975	13	0.143058			
Total	10.09868	16				

Table 48. One way ANOVA Secchi disk Lake Kivu water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	11.4	2.28	0.107
Out of the cage	5	14.9	2.98	0.057
Hot spring	2	6.6	3.3	0.02
Nyamwenda	4	7.95	1.9875	0.117292

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.679469	3	1.22649	14.31874	0.000287	3.490295
Within Groups	1.027875	12	0.085656			
Total	4.707344	15				

Table 49. One way ANOVA Chlorophyll a surface water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	20.72	5.18	3.06656
Out of the cage	4	14.504	3.626	1.42376
Hot spring	2	7.696	3.848	29.61421
Nyamwenda	3	11.84	3.946667	0.029205

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5.597876	3	1.865959	0.38925	0.763653	3.862548
Within Groups	43.14358	9	4.793731			
Total	48.74145	12				

Table 50. One way ANOVA Chlorophyll a middle water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	18.648	4.662	4.285883
Out of the cage	4	18.944	4.736	6.483584
Hot spring	2	10.952	5.476	5.300768
Nyamwenda	4	7.4	1.85	2.767205

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	26.76669	3	8.922229	1.943384	0.186633	3.708265
Within Groups	45.91078	10	4.591078			
Total	72.67747	13				

Table 51. One way ANOVA Chlorophyll a bottom water in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	18.352	4.588	0.788544
Out of the cage	4	12.136	3.034	0.255547
Hot spring	2	7.696	3.848	4.3808
Nyamwenda	3	5.624	1.874667	2.832917

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	13.55071	3	4.516904	3.084637	0.082757	3.862548
Within Groups	13.17891	9	1.464323			
Total	26.72962	12				

Table 52. One way ANOVA Chlorophyll a surface water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	3	4.144	1.381333	2.832917
Out of the cage	2	8.584	4.292	1.0952
Hot spring	2	8.288	4.144	8.586368
Nyamwenda	4	13.32	3.33	4.110651

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	14.08958	3	4.696527	1.187733	0.381317	4.346831
Within Groups	27.67935	7	3.954194			
Total	41.76894	10				

Table 53. One way ANOVA Chlorophyll a middle water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	1	3.256	3.256	
Out of the cage	2	5.032	2.516	0.394272
Hot spring	2	7.010526	3.505263	0.594624
Nyamwenda	3	4.144	1.381333	2.832917

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6.308554	3	2.102851	1.263974	0.3991	6.591382
Within Groups	6.65473	4	1.663683			
Total	12.96328	7				

Table 54. One way ANOVA Chlorophyll a bottom water in November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	3	10.36	3.453333	3.270997
Out of the cage	5	12.432	2.4864	4.713741
Hot spring	2	9.176	4.588	0.394272
Nyamwenda	4	9.472	2.368	3.037355

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8.554242	3	2.851414	0.816947	0.513423	3.708265
Within Groups	34.90329	10	3.490329			
Total	43.45754	13				

Table 55. One way ANOVA Chlorophyll a surface water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	25.00664	5.001328	8.112009
Out of the cage	4	19.018	4.7545	3.454088
Hot spring	2	8.288	4.144	8.586368
Nyamwenda	4	13.32	3.33	4.110651

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.012335	3	2.337445	0.403459	0.753447	3.587434
Within Groups	63.72862	11	5.793511			
Total	70.74096	14				

Table 56. One way ANOVA Chlorophyll a middle water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	12.78556	3.196389	5.956418
Out of the cage	3	13.22133	4.407111	1.609538
Hot spring	2	7.010526	3.505263	0.594624
Nyamwenda	3	4.144	1.381333	2.832917

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	14.35258	3	4.784193	1.39946	0.312029	4.066181
Within Groups	27.34879	8	3.418599			
Total	41.70137	11				

Table 57. One way ANOVA Chlorophyll a bottom water in December

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	12.46525	3.116313	5.231946
Out of the cage	4	8.425441	2.10636	3.738862
Hot spring	2	9.176	4.588	0.394272
Nyamwenda	4	9.472	2.368	3.037355

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9.45695	3	3.152317	0.865575	0.490448	3.708265
Within Groups	36.41876	10	3.641876			
Total	45.87571	13				

Table 58. One way ANOVA for organic matter in October

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	4	30.90278178	7.725695445	0.672533953
Out of the cage	4	23.57292039	5.893230098	1.738301851
Hot spring	3	17.95334325	5.98444775	0.656545979
Nyamwenda	4	28.95348252	7.238370631	3.747410097

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9.455208386	3	3.151736129	1.752041432	0.214241153	3.587433702
Within Groups	19.78782966	11	1.798893606			
Total	29.24303805	14				

Table 59. One way ANOVA for organic matter November

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
In the cage	5	37.87347059	7.574694118	1.742172511
Out of the cage	5	27.59915264	5.519830529	1.019843393
Hot spring	2	4.336399474	2.168199737	1.942599215
Nyamwenda	4	50.2847131	12.57117827	142.9369299

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	179.356287	3	59.78542901	1.623863263	0.23584392	3.490294819
Within Groups	441.8014525	12	36.81678771			
Total	621.1577395	15				