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MSc in Biodiversity Conservation and Natural Resources Management

Evaluating the Impacts of Rusumo Waterfall on Fish Communities of Akagera River, Kirehe District, Rwanda

Thesis submitted to the University of Rwanda: College of Science and Technology in partial fulfillment of the requirements for the award of the Master's Degree of Science in Biodiversity Conservation and Natural Resources Management.

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DECLARATION

This dissertation is original research carried out under the School of Sciences, College of Science and Technology, University of Rwanda for the Masters of Science in Biodiversity Conservation and Natural Resources Management Programme. I, Theodore Nshimiyumuremyi, declare that this dissertation contains my findings and has never been submitted for any other award in this or any other institution of higher learning. No portion of my dissertation has been copyrighted previously unless properly referenced.

Signature…………………………… Date…………………………

Theodore Nshimiyumuremyi

APPROVAL

I certify that this research project entitled **" Evaluating the Impacts of Rusumo Waterfall on Fish Communities of Akagera River, Kirehe District, Rwanda"** was done under my supervision and has been submitted for examination with my approval**.**

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DEDICATION

I dedicate this dissertation to Almighty God for blessings and gifts of life and strength to accomplish this study

Special dedication to my supervisors for their guidance, patience, and belief in my abilities

This study is also dedicated to my family for their endless love, understanding, whose unwavering support and encouragement have been my anchor throughout this journey.

The last, not the least I dedicate this dissertation to my dear classmates and workmates who have shared the professional adventure with me. Their support, insightful discussions, and shared commitment to excellence have been invaluable throughout this journey. Thank you all for your encouragement and friendship.

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Not the least of all, I owe so much to my whole family for their undying support and their unwavering belief that I can achieve so much. Unfortunately, I cannot thank everyone by name because it would take a lifetime but, I just want you all to know that you count so much. Had it not been for all your prayers and benedictions; were it not for your sincere love and help, I would never have completed this thesis. So, thank you all.

ABSTRACT

The aquatic biodiversity performs several critical roles in ecosystem functioning through their numerical abundance, taxonomic diversity, and trophic significance. This study aimed to evaluate the impacts of Rusumo Waterfall on fish communities of Akagera River by assessing the spatial distribution of fish species in two biotopes: upstream and downstream from Rusumo Waterfall, Akagera River, Kirehe District, Rwanda. Primary data were collected at four fishing stations using the stationary-point-count technique, and fish were identified directly on the field and in the laboratory using morphological analysis. The secondary data for fish of Rwanda was obtained from Rwanda Biodiversity Information Systystem (RBIS,2024). The results showed that a total of 1836 fish individuals from 14 species richness belonging to 9 families were recorded from 4 fishing stations. Four fishing stations were strictly selected, two at each biotope from Rusumo waterfall. The results showed that from all recorded fish individuals, they were dominated by *Oreochromis niloticus* with 680 species abundance represented by 37.04%, followed by pollimyrus nigricans with 540 species abundance representing 29.41% of all sampled fish individuals. Results also showed that species richness is higher at downstream with 14 species compared to upstream with 5 species . The downstream also has higher fish diversity with Shannon Wiener Index (H) of 1.5 compared to the upstream represented by H of 0.3, and also the species from downstream are higher evenness distributed with evenness (J) of 0.6 than upstream with 0.2. Among fifteen identified fish species, four are threatened as listed on the IUCN Redlist. Those are *Labeo victorianus* (Critically endangered), *Haplochromis erythromaculatus* (Endangered)*, and Cyprinus carpio* (*Vulnerable*), and *Synodontis ruandae* (Vulnerable) which also recently recorded in other hydrological network in Rwanda, beyond Akagera River. This research confirms that there are impacts of Rusumo Waterfall acting as a natural bio-geographic barrier for fish dispersal and preventing species exchange among regions as demonstrated by (Torrente-Vilara et al., 2011). Further studies are needed to assess the impacts of local environmental conditions, and physico-chemical variables on the composition and structure of fish assemblages in the interface of waterfall. Finally, the researcher calls the catchment conservation and management planners to take into account the sustainable management of freshwater hydrological networks, by considering the waterfall as a natural barrier for fish distribution.

Keywords: Fish Communities, Rusmo Waterfall, Akagera River, Kirehe District, Rwanda

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LIST OF ABBREVIATIONS AND ACRONYMS

ARCOS	Albertine Rift Conservation Society
BEF	Biodiversity and Ecosystem Functioning
BES	Biodiversity and Ecosystem Services
CR	Critically Endangered
EN	Endangered
H	Shannon-Wiener Index
IUCN	International Union for Conservation of Nature
N	Species Abundance
NISR	National Institute of Statistics of Rwanda
REMA	Rwanda Environment Management Authority
S	Species Richness
UNEP	United Nations Environmental Programme
VU	Vulnerable
WWF	World Wildlife Fund

CHAPTER I: INTRODUCTION

1.1. Background

The aquatic biodiversity performs several critical roles in ecosystem functioning by their numerical abundance, taxonomic diversity, and trophic significance (Bernhardt & Connor, 2021). The link between biodiversity and ecosystem functioning (BEF) and between biodiversity and ecosystem services (BES) has also increased in the past decades as argued by various scientific research (Bernhardt & Connor, 2021). Freshwater ecosystems are home to a greater biodiversity of insect and fish fauna (Lévêque, 1997). All those species play a vital role in in ecological functioning and processes for environmental and human health through ecological importance they provide.

Water is very important for ecosystem functioning and natural processes. Water links and maintains all ecosystems on the planet, mainly enhancing natural processes such as the nitrogen cycle; carbon cycle and water cycle (WWF, 2016). Water provide a permanent dwelling for species that live within it, and provides a temporary home or breeding ground for multiple fishes, insects, and other water-birthed organisms; and provides the nutrients and minerals necessary to sustain physical life. Also, Water that is available for human use is that of groundwater, lakes a,nd rivers. As human activities step forward in interacting connected landscapes, the aquatic biodiversity is damaged where the water resources are affected and sometimes broken (Díaz et al., 2006). Apart from water available and supply around the world, water quality is still a big issue to managed.manage sources and resources in Rwanda are abundant that comprise 101 lakes, hundreds of rivers, marshlands, and groundwater, also has a very dense hydrological network (NISR, 2019). Nile Basin is one of these networks that covers 67% of the land area in Rwanda and makes off 90% of Rwanda's national water resources (Green Rwanda,2020). Akagera River, or Alexandra Nile with a total length of 597 km (371 mi), is an East African river, forming part of the upper headwaters of the Nile system and carrying water from from its source located in Lake Rweru in Rwanda (Nzeyimana Lazare, 2003). Akagera River has a total catchment area of 60,000 km2 that supports 16.5 millio people in Rwanda and downstream (Khan et al., 2019).

Akagera Wetland complex is made of biodiversity changes in various ecosystems such as wetlands, and marshlands that support life (REMA, 2019). This complex has high diversities o plants, mammals, fishes, birds, and various macroinvertebrates, some are endemic in this area (STATE OF THE RIVER NILE BASIN, 2012). Most of the aquatic biodiversity of Akagera River is bio-indicators of environmental changes and habitat disturbances like amphibians, fishes, and benthic macroinvertebrates. Some studies showed that the Akagera river has waterbodies that occupy 30% of the wetland's surface area (Akagera Wetland Complex), hippo grass and *Cyperus papyrus* are also predominant, representing 29.8% and 29%, respectively (Ndayisaba et al., 2017). The high diversity of Plants in the Akagera river system is the most important in ecosystem integrity "ecosystem maintain and support its ecological processes and diverse community of life in presence of disturbance"(Plesnik et al., 2013). High plant diversities means high primary production of the ecosystem as well as habitat stability (Haddad, 2015). Moreover, Akagera river has Rusumo waterfall, one main natural barrier for aquatic biodiversity but also play crucial role of hydrological dynamics of this important transboundary river system.

1.2. Problem Statement

There no research in Rwanda conducted on assessing the impact of Waterfall on freshwater biodiversity, particularly fish communities. Rwanda is facing increasing degradation of watersheds and water bodies as a result of unsustainable land use practices driven by the demands of intensified socio-economic development and continuing population pressures on….(Nambajimana JD et al., 2020). The sustainable use of water in areas such as agriculture and hydropower requires more attention by policymakers to safeguard this indispensable resource (REMA, 2017). Water hyacinth invades aquatic biodiversity including water bodies of the Akagera river system and the Akagera wetland complex. The decreasing of native fish species in the Nyabarongo-Akagera river system due to the invasion and increase of predator species (UNEP, 2014) is also a challenge. Various articles showed that waterfalls have serious impacts on biodiversity loss due to species isolation and several impacts on river ecosystems by altering water flow and creating obstacles for aquatic species living in the affected water system (Simonov et al, 2019). Negative impacts of waterfall are also explored on hydraulics, hydrology, and freshwater animal (fish, and macroinvertebrates) performance and population dynamics (Figueiredo et al., 2021). There is gap and lack of information on impacts of Rusumo waterfall on fish communities of Akagera river. To overcome environmental problems associated to lack of information on the impacts of waterfall on fish communities in Rwanda, this study focused on impact assessment of Rusumo waterfall by providing avail information on the structure and assemblages of fish communities of Akagera river from the two biotopes of upstream and downstream and later contribute for science-policy-practice interface on freshwater ecosystems conservation.

1.3. Research goal

The research aims to document the relationship between fish assemblages and natural barriers like the Rusumo waterfall of the Akagera river and identify possible conservation and management strategies for fish communities in streams with waterfalls.

1.4. Research Objectives

1.4.1. Main Objective

The main objective of this study is to assess the impacts of the Rusumo waterfall on the fish communities of the Akagera River. This study aims to assess the spatial distribution of fish species in two biotopes: upstream and downstream of Rusumo Waterfall, Akagera River, Kirehe District, Rwanda.

1.4.2. Specific Objectives

- To determine the fish assemblage structure and composition differences between two biotopes (upstream and downstream from the Rusumo Waterfall).
- Identify the threatened fish species from the two biotopes.
- To assess the spacial distribution of these threatened fish species by considering the historical record across Rwanda territory (hydrological networks) and identify the potential recommendations for wild fish species conservation and catchment management.

1.4.3. Research Questions

- What is the difference in fish assemblage structure and composition between the two biotopes?
- What fish species are threatened by the IUCN Redlist, and how are they distributed from the two biotopes?
- How are these threatened fish species recently detected in different waterbodies of Rwanda?

1.4.4. Research Hypothesis

We hypothesize that there is sisgnificance difference in fish assemblage structure and composition between the two biotopes, with great indication to spacial distribution of fish species in Akagera river as well as on the different hygrological networks of Rwanda.

I.5. Justification of the study

The research entitled "Evaluating the Impacts of Rusumo Waterfall on Fish Communities of Akagera River". is relavant to the Masters of Biodiversity conservation and natural resources management, under the School of Sciences, College of Science and Technology, University of Rwanda. Currently, no the similar research , previous study or publication done at Akagera river and other freshwater ecosystem of Rwanda. Therefore, this study was done to address this gap by providing avail information on the Impacts of Rusumo Waterfall on Fish Communities of Akagera River to contribute to the science-policy-practice interface for freshwater ecosystems conservation. Moreover, this study aimed to contribute valuable insights into the ecological significance of waterfalls towards fish communities.

CHAPTER II: LITERATURE REVIEW

2.1. Freshwater Ecosystems

Approximately 70% of Earth's surface is occupied by water of which 97.5% is salty water, while 2.5% is freshwater (Mishra, 2023). The freshwater ecosystem is a subset of Earth's aquatic ecosystems, and it is divided in two main groups such as lentic (stagnant water like lakes, ponds, etc) and lotic medium (flowing water like rivers, streams, etc) (Balasubramanian, 2016).Freshwater ecosystems are important for many reasons including their vital ecosystem services for humans such as providing (drinking water, etc), regulative services (flood control, and climate regulation, etc), supportive services (nutrient cycle, food production, etc), and aesthetic values (recreational sites like swimming pool, beach, etc) (Guerquin et al., 2020). Therefore, Water is prime natural resources that fulfills human needs, ecosystem functioning and serves as a home wide biodiversity that depend on it (Mishra & Dubey, 2015).

2.2. Fish ecology and community

The study about the story of fishes is like studying the story of changing continents, climates, species mass extinctions and changing faunas and floras throughout time (Olden et al., 2011). Fish like other aquatic biodiversity, live permanently in water and interact with other living things as well as their physical environments (Dempsey, 2011). Fish communities are influences factors such slopes, waterfall, vegetation, physica-chemical matters, and other fauna that affect population structure, movement patterns, and residence time (Bruno, 2016). Moreover, River fragmentation associated to instream barriers leads to biodiversity loss, especially freshwater migratory fish (Consuegra et al., 2021). Therefore, fish abundance, assemblages and community composition are essential to consider in wild fish conservation and management (Barrientos & Allen, 2008).

2.3. Waterfalls as natural Barrier for fish distribution

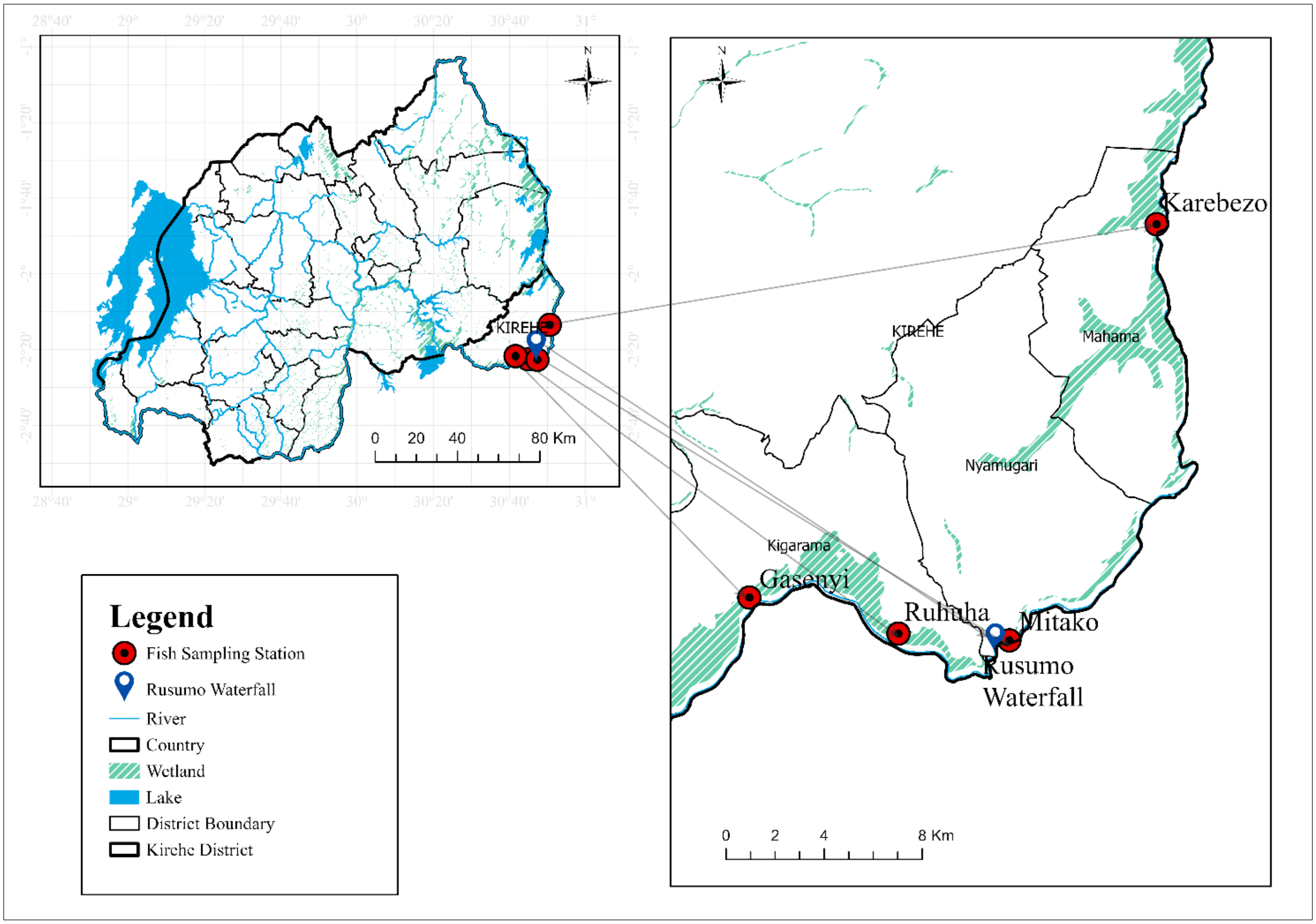
Waterfalls are conspicuous geomorphological features with different structure, complex , dynamics and multiphase flows from a river and other water bodies (Ortega-Jimenez et al., 2020). Waterfall is natural barrier for migratory aquatic fauna, and act as isolation, which is also recognised as a fundamental factor in determining the distribution of species (Torrente-Vilara et al., 2011). Moreover, waterfalls also influence fish species distribution and segregation of fish assemblages in consdideration of of two biotopes: upstream and downstream of rivers where composition and structure of the fish differ between biotopes (Silva et al., 2016).

CHAPTER III: MATERIALS AND METHODS

3.1. Description of the Study Area

Kirehe district of Rwanda is geographically located at a latitude of 2,263273S, longitude of 30.641561E, and Elevation of 1587.69 meters. Kirehe District extends over a total area of 1,118.5 Km2 with about 164,012 male and 176,971 female inhabitants equaling 340,983 of its total population, Agriculture and livestock are major economic activities in Kirehe district that occupy at least 90% of the population (NISR, 2013). Kirehe is characterized by lowly undulating hills separated by valleys some of which are swampy. It has very few streams and lakes (Rwampanga, Cyambwe, and Nyabugongwe lakes, etc) with other sources like dams, Marshland clearance, and water ponds, while the principal watercourse of the District is the Akagera River. Kirehe population, 67% has access to improved water and, the average distance covered by persons to access water is 800 meters, which is why water is an issue in the Kirehe district. It is dominated by savanna vegetation such as acacia where natural forest is likely to disappear (IBCGroup, 2020).

Environmental conservation in the Kirehe district poetizes forestation (progressive terraces, tree planting, radical terraces), the use of Biogas and other renewable energy (Solar energy), protect lake shores by bamboo forest cover to manage logging and soil erosion. This research study was conducted in two selected biotopes (upstream and downstream) from the Rusumo waterfall of Akagera River. Rusumo waterfall is geographically located at 2°22′31″S 30°47′33″E Coordinates, in the Kirehe district of Rwanda. Moreover, Rusumo waterfall is located at the common transboundary border of Rwanda and Tanzania. The falls are approximately 15 m high and 40 m wide and have formed on Precambrian schists and quartz–phyllites. The Sampled fishing stations are found in wetlands surrounding the Akagera River, these wetlands are characterized by stagnant water and papyrus vegetation is the dominant plant species. Therefore, this research was conducted in 2 sites from upstream in the Kigarama sector and 2 sites from downstream in the Nyamugari and Mahama sectors.



Map 1: Study area and sampled fishing stations

3.2. Research Approach and Methods

Fish sampling was carried out from 8th-13rd October 2021 representing 2 biotopes across the Rusumo waterfall. The sampling followed Stationary-point-count technique visiting once each sampling site (Kualiti et al., 2015). Four fishing stations was temporal surveyed throughout the wetland covering selected fish sampling station of Akagera river, 2 fishing stations were selected from each biotope (upstream and downstream). Fish were caught at each location over the course of the sampling period using a seine fishing net with a mesh size of 1 cm, a length of 2.5 m, and a width of 2 m. Simple fish collecting methods were used, where two people walking parallel through the water with a seine net forming a U-shape behind them, one on each end. The trawling was done three times in each sampling station.

Fish species identification was done by morphometrical analysis and using the field guide (Ibañez et al., 2007). This involved the measurement and counting of characteristic external organs of sampled fish and examining the color pattern, morphology, lateral lines, fins and mouth, and character of the teeth and scales (Ezeafulukwe et al., 2015). In addition, all unidentified fish on the field were photographed and some samples were collected, conserved in a solution of formaldehyde for subsequent identification in the laboratory (Azmi & Geok, 2016). For identification, the classification of sampled fish followed the taxonomic keys, Check-list of fishes of Rwanda (De Vos, L., et al 2001), Check-list of the Freshwater Fishes of Africa CLOFFA 1 (Daget J, et al. 1984; FishBase, 2018), Check-list of the Freshwater Fishes of Africa CLOFFA 2 (Daget J, et al. 1986) Check-list of the freshwater fishes of Africa CLOFFA (Lévêque, C. et al, 1984) and FISHBASE (short description, occurrences, pictures…).

Moreover, historical data on threatened species spatial distribution in Rwanda was obtained from the Rwanda Biodiversity Information System (RBIS, 2024), requested and authorized for use by the Center of Excellence in Biodiversity and Natural Resource Management at the University of Rwanda. Desk study methods was used for exploring findings from previous research was applied, particularly on analyses of the further impacts of waterfalls on the fish species' ecology and distribution in their natural habitats.

Figure 1: Fish identification on the field, Mitako fishing station, Akagera river

The study also accounted the map production showing the distribution of fish species and sampling stations.The data were collected using GPS Garmin on fields from each sampling station, and GPS coordinates of hsitaorical data on threatened species distribution in Rwanda obtained from Rwanda Biodiversity Information System. ArcGIS pro 3.3 was used in data processing and analysis to produce study area and specie historical distribution map. Details about the procedures and methods are show in the figure 2.

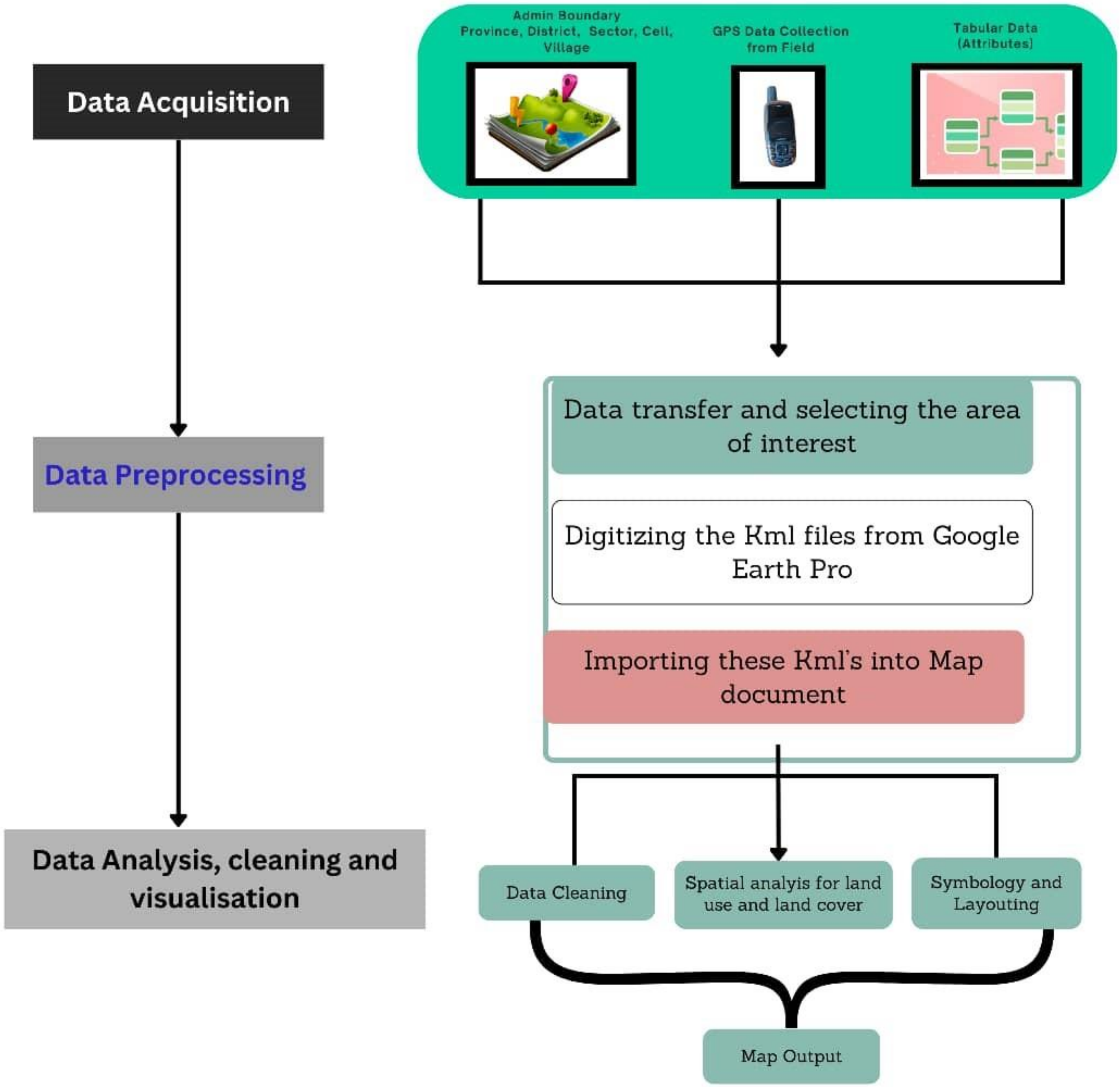


FIGURE 2: ***DIAGRAM SHOWING THE MAP PRODUCTION PROCESSES***

3.3. Data Processing and Analysis

The database was created using Microsoft spreadsheet of Microsoft Excel. Data was analyzed for species diversity index, statistical analysis, and geospatial analysis for the fish community from the two biotopes (downstream and upstream):

Analysis of Species Diversity

Shannon -Wiener diversity index (H')

H' was applied to indicate the species diversity of the fish communities from two biotopes, and was calculated to get a better quantitative description of these communities.

Equation 1: Shannon -Wiener diversity index (H') was calculated as: $H' = -\sum (ni/N)\ln(ni/N) = -\sum Pi * \ln pi$ (Shannon-Wiener 1963), Where, N =Total no of species., ni = number of individuals of species., Pi = ni/N,and Ln = Natural logarithm

Evenness index (J)

Species evenness refers to closeness in the number of each species in a community. It was calculated by the following formula: **Equation 2:** Species evenness (J) , $J=H'/\ln S$ (Odum1967), Where, H' = Shannon -Wiener Diversity Index, S = numbers of species.

Statistical analysis

The Collected data was analyzed using Microsoft Excel. Microsoft Excel spreadsheet was also used in data entry, data processing, drawing graphs and tables, and interpreting data. The chi-square test was performed to determine whether there was a statistically significant difference between the mean from the species composition in two categories (upstream and downstream).

Equation 3: Chi Square Formula

The Chi-Square is denoted by χ^2. The chi-square formula is: $\boldsymbol{\chi^2 = \sum(O_i - E_i)^2/E_i}$, where O_i = observed value (actual value) and E_i = expected value.

Geospatial Analysis

GIS software is used for the analysis of geospatial data. ArcGIS was used in geo-referential data processing, geographical map production, and data interpretation for species distribution.

CHAPTER IV: RESULTS

4.1. Results for the fish assemblage structure and composition differences between two biotopes.

In total, 1836 individuals from 14 species richness belonging to 9 fish families were recorded from four sampled fishing stations of two biotopes from Rusumo Waterfall of Akagera River (Table 1).The dominant species identified is *Oreochromis niloticus* accounting for 680 individuals (37.04% of the total sample), followed by *Pollimyrus nigricans* with 540 individuals (29.41%). This study highlights the importance of the Akagera River as suitable habitat for aquatic biodiverse habitat, particularly in the context of fish populations.

The findings also indicated a notable significant difference in species richness between the upstream and downstream areas of the river. Downstream sampling is higher with 14 species, compare to upstream with only 6 species (Figure 3). This disparity is further supported by the Shannon Wiener Index, which measured the higher fish diversity from downstream (H = 1.5) compared to upstream (H = 0.3). Additionally, species evenness was also higher at downstream (J = 0.6) than upstream (J = 0.2), suggesting a more balanced distribution of species in the downstream biotope.

Statistical analysis confirmed significant differences in fish species composition between the two biotopes. The calculated Chi-square test results ($\chi^2 = 7540.5$; df = 14; $p < 0.0001$) indicates the distinct ecological dynamics present in the upstream and downstream of the Akagera River. These findings not only contribute to our understanding of Akagera river but also have implications for conservation and management strategies in the region.

Table 1: Status of richness, abundance, diversity of samplesd fish species.

No	Species name	IUCN status	Biotope		Total Abundance	Total Relative Abundance (%)
			Downstream	Upstream		
1	*Oreochromis niloticus*	*LC*	57	623	680	37.04
2	*Pollimyrus nigricans*	*LC*	540		540	29.41
3	*Gnathonemus longibarbis*	*LC*	254		254	13.83
4	*Schilbe intermedius*	*LC*	192		192	10.46
5	*Labeo Victorianus*	*CR*	52		52	2.83
6	*Protopterus aethiopicus*	*LC*	30	18	48	2.61
7	*Clarias gariepinus*	*LC*	15	21	36	1.96
8	*Synodontis ruandae*	*VU*	16		16	0.87

9	*Petrocephalus catostoma*	*LC*	8		8	0.44
10	*Cyprinus Carpio*	*VU*	2	1	3	0.16
11	*Haplochromis Ertythromaculatus*	*EN*	1	2	3	0.16
12	*Acapoeta tanganicae*	*LC*	2		2	0.11
13	*Bagrus docmac*	*LC*	1		1	0.05
14	*Mastecembelus frenatus*	*LC*	1		1	0.05
	Total		1171	665	1836	100
	Species richness (S)		14	5	14	
	Evenness (J)		0.6	0.2	0.6	
	Shannon Wiener index (H')		1.5	0.3	1.6	

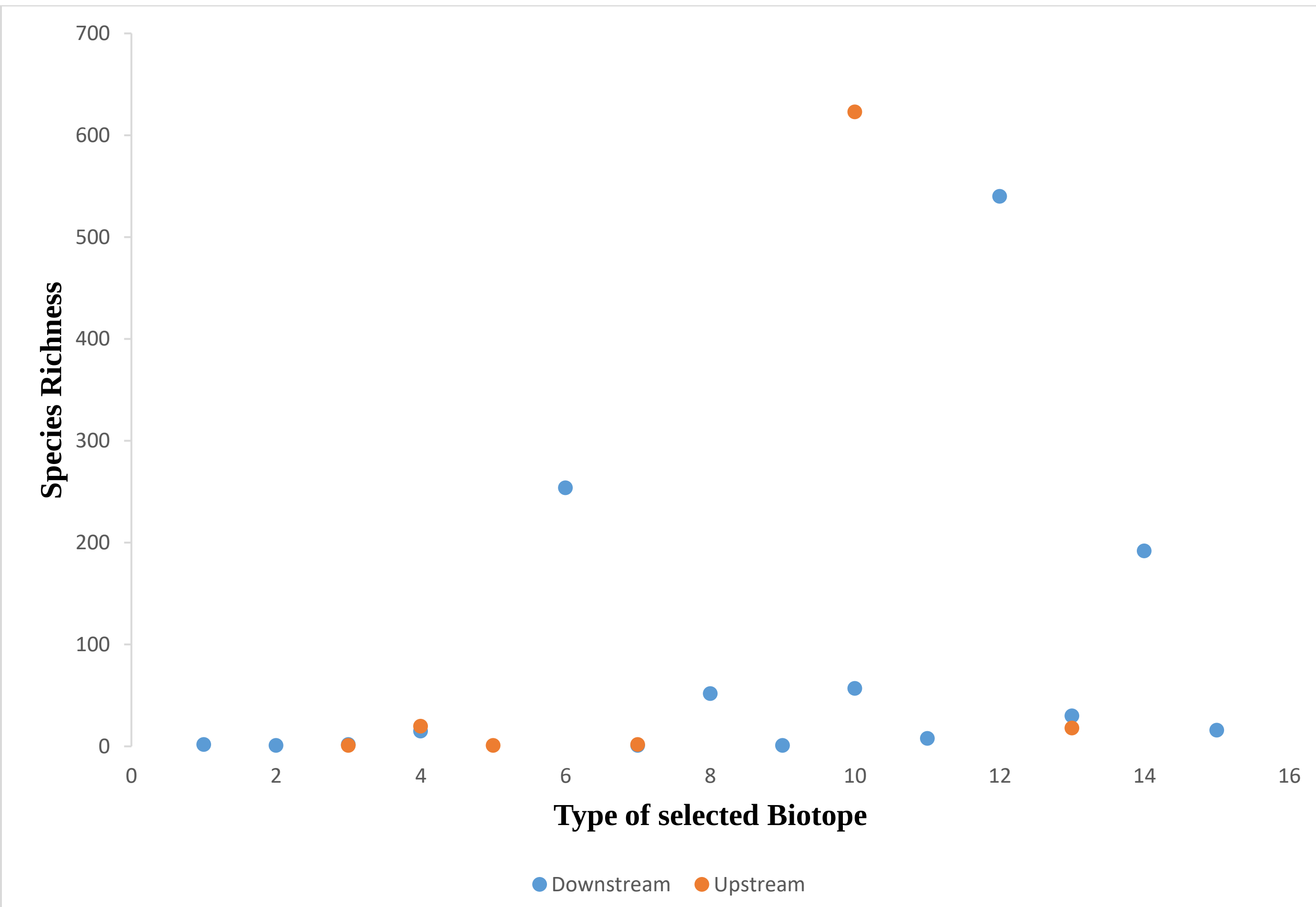


Figure 3: Fish species richness from the two biotopes

4.2. Results from identified threatened fish species from the two biotopes.

There four threatened fish species were recorded from the two biotopes (downstream and upstream) from Rusumo Waterfall of Akagera River. Among the four recorded threatened species, *Haplochromis erythromaculatus* is classified as endangered to the IUCN Redlist and is widespread across both upstream and downstream biotopes. Similarly, the *Cyprinus carpio* (common carp) is vulnerable and appears in all sampled areas.

In contrast, the critically endangered *Labeo victorianus* and the vulnerable *Synodontis ruandae* (Endemic to Rwanda) are restricted to the downstream area only. This distribution highlights the ecological pressures faced by specific species in these distinct habitats, with downstream conditions potentially offering different resources or challenges compared to upstream.

The presence of these threatened species indicates the need for conservation efforts in the region for freshwater biodiversity conservation. Protecting the habitats around the Akagera River, especially near the Rusumo Waterfall, is crucial for maintaining the populations of these threatened species. Overall, the Akagera River ecosystem reflects both richness in fish species and the urgent need for management measures to ensure the survival of its threatened species.

Table 2: Occurrence of four identified four threatened fish species from the two biotopes

No	Family	Fish Species	Downstream	Upstream	IUCN Redlist
2	Cyprinidae	*Labeo victorianus*	*		CR
1	Cichlidae	*Haplochromis erythromaculatus*	*	*	En
3	Mochokidae	*Synodontis ruandae*	*		Vu
4	Cyprinidae	*Cyprinus carpio*	*	*	Vu

4.3. The historical map of Rwanda showing the threatened fish species recorded from Akagera River.

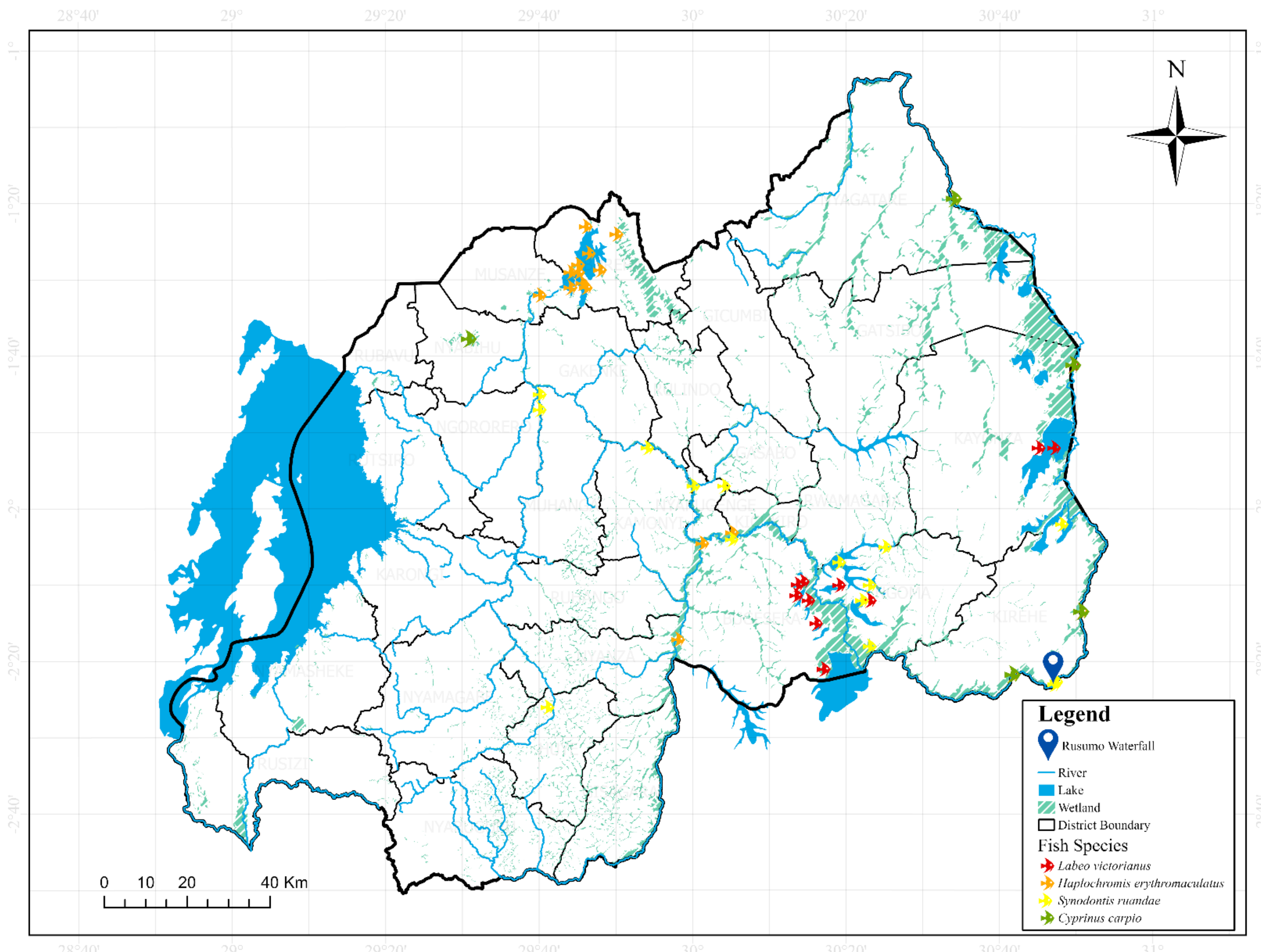
The results showed that the four threatened fish species recorded from the Akagera river in the Kihere district, they historically displayed a wide distribution across the hydrological network of Rwanda including rivers, lakes, wetlands, and their tributaries from Akagera basin (**Map 2**). Among these, *Synodontis ruandae* which is endemic to Rwanda, shows the highest level of dispersion, indicating a robust adaptability to different aquatic environments within the Akagera basin. This wide distribution support the idea that *Synodontis ruandae* may thrive in various water conditions, benefiting from diverse habitats throughout the country.Moreover, endangered *Haplochromis erythromaculatus* is among the fish species with the highest distribution showing also their historical record in Burera and Ruhondo,twin lakes in Northern Province of Rwanda.

Despite that recorded *Cyprinus carpio* listed as vulnerable on the global IUCN Red List of threatened Species, the species also recognized as the invasive species listed by Invasive Specialist Group of the World Conservation Union (IUCN). The species is also widely distributed in the Akagera basin. Thus, the presence of *Cyprinus carpio* can have both ecological benefits and challenges, as it may compete with native fish for resources, impacting local biodiversity.

In contrast, *Labeo victorianus* categorized as critically endangered at global IUCN Red List of threatened Species, it exhibits the lowest dispersion restricted to the Akagera river only. This limited biogeographical range is alarming that led the vulnerability of this species from anthropogenic pressure and other environmental issues. Its restricted habitat highlights the need for urgent conservation efforts to protect its remaining populations and address the environmental factors contributing to its decline.

Historically, Rwanda's hydrological network has provided suitable habitats for these threatened species. However, due to anthropogenic factors such as habitat destruction and climate change may have the adverse impacts to suitable ecosystems of these fish species. This might have direct implications for the survival of sensitive species like critically endangered *Labeo victorianus*, which requires specific environmental conditions to survive.

Referring to this research findings, it is clear to call for the for the conservation efforts focus on habitat protection and restoration throughout the Akagera basin. Also, species population needs to be sustained or maintained, especially supporting the diverse fish populations, particularly the threatened species. Collaborative efforts among local communities, government agencies, and conservation organizations will be vital in fostering a sustainable environment for these fish and the broader ecosystem.



Map 2: The historical map of Rwanda showing the presence of four threatened fish species from two biotopes of Akagera River at Rusumo Waterfall.

CHAPTER VI: DISCUSSION

5.1. Fish assemblage structure and composition differences between two biotopes.

Oreochromis niloticus, commonly known as Nile tilapia is notable for its high abundance compared to other recorded fish species, this is primarily due to it is reported to be intentionally dispersed worldwide with high adaptation to the tropical freshwater environments (Canonico et al., 2005). This species live in various habitats, demonstrating remarkable resilience and presence from the two biotopes. Its preference in different biotopes enhance its ecological significance and the role it plays in local fish communities, where it often dominates in terms of fish quantity and abundance

The distribution of fish species is significantly influenced by geographical barriers, such as waterfalls, which create disparities in species richness between upstream and downstream environments. Generally, downstream areas exhibit greater species richness than upstream areas, a trend that can be attributed to the restrictive nature of waterfalls (Torrente-Vilara et al., 2011; Blackburn & Park, 2021). These natural barriers impacts the movement of fish, thereby limiting their dispersal and leading to a reduction in diversity upstream (G. D. Grossman, R. E. Ratajczak Jr. & Farr, C. M. Wagner, C. M. Petty, 2010). This study indicates that waterfalls can effectively fragment aquatic ecosystems, resulting in distinct fish assemblages based on their locations (Torrente-Vilara et al., 2011).

Additional, Waterfalls are physical vertical barriers within river systems, spreading the upstream migration of various fish species. This obstacles prevents the exchange of species between different river sections, which can further exacerbate diversity loss in upstream habitats (Jubb et al., 2023). As fish populations become isolated, their genetic diversity may diminish, making them more susceptible to environmental changes and less able to adapt to new challenges (Washington Department of Fish and Wildlife, 2009). Consequently, the ecological dynamics of these riverine environments become increasingly complex.

The impact of waterfalls extends beyond simple barriers; it also impacts connectivity and contributing to the decline of migratory fish populations (McIntyre et al., 2015). In these challenging conditions, fish may develop unique behavioral or morphological traits that enable them to navigate against strong water currents (Kasumyan & Pavlov, 2023). This adaptation is crucial for sustaining fish populations upstream, as it allows for some level of connectivity between segmented habitats. The importance of understanding how physical barriers shape fish distributions and community structures is also fundamental in fishery and water resources management for sustainability planning (Zarri et al., 2022; Tutzer et al., 2022).

Moreover, recognizing the role of waterfalls as bio-geographic barriers is essential for fish conservation and water resource management. These natural features significantly affect fish distribution, migration, and biodiversity in freshwater ecosystems. As conservation efforts evolve, it is critical to consider the ecological implication of such barriers, promoting strategies that enhance connectivity and protect diverse aquatic communities. This understanding will ultimately aid in the sustainable management of freshwater resources, ensuring the viability of fish populations in the face of environmental change.

5.2. Identification of the threatened fish species from the two biotopes

Based on field observations and data from this research (2021), it is clear that Akagera River is critical for biodiversity, particularly for several fish species of of international importance and conservation concerns such as the Critically endangered *Labeo victorianus* (Ningu), Engengered *Haplochromis erythromaculatus, and Vulnerable species* such as *Synodontis ruandae*, and *Cyprinus carpio*. Among these, the *Labeo victorianus* (Ningu) relies heavily on shallow, substrate-rich habitats, which are essential for its breeding and feeding (Lailatul Mufidah, 2021). Its presence highlights the ecological importance of preserving these specific environments to ensure the survival of such species.

Additionally, *Haplochromis erythromaculatus* adapting to shallow waters along vegetation (ARCOS, 2021), *Synodontis ruandae* preferring shallow waters and vegetation along the edge of the water (REMA, 2019) and *Cyprinus carpio spending* it whole lives in pools in streams, lakes, and reservoirs preferring larger, warmer, slower moving waterbodies but they are tolerant and hardy fish that thrive in a wide variety of aquatic habitats (Kloskowski, 2011) associated to the hydrology and physical characteristics of the Akagera River (ARCOS, 2021).

Research indicates that the presence of waterfalls within the Akagera River ecosystem can affect the distribution of recorded of threatened species, acting as natural barriers that limit their movement and dispersal. This finding emphasizes the need for conservation strategies that consider the unique hydrological features of the river and their impact on aquatic biodiversity.

5.3. The historical distribution of threatened fish species recorded from the Akagera River across different Hydrological Network of Rwanda.

A historical perspective on river systems is crucial for understanding the dynamics of fish assemblages. Since 1979, various fish surveys have been conducted in Rwanda, aiming to document and analyze the state of aquatic biodiversity (De Vos et al., 2001). My research specifically utilizes georeferenced data from 1990, providing a crucial temporal framework for examining changes in fish populations over time. This data allows for the identification of trends and potential impacts of environmental changes on fish species in Rwanda's river systems.

The study revealed that four threatened fish species *Labeo victorianus* (Ningu), *Haplochromis erythromaculatus*, *Cyprinus carpio*, and *Synodontis ruandae* are found across various water bodies in Rwanda (De Vos et al., 2001). These species are largely restricted to the hydrological network of the Nile basin, highlighting the ecological significance of this region for fish biodiversity. Understanding their distribution is essential for conservation efforts, as these species are vulnerable to habitat degradation and environmental changes.

Additionally, this research compiled the historical occurrences and distribution data of these threatened fish species specifically from the Akagera River. While this information is valuable, it is insufficient to conclusively determine whether these species still inhabit their original water bodies throughout Rwanda, apart from the Akagera River. This gap in updated information recommends the need for ongoing monitoring and further research to ensure the conservation of these species and their historical habitats.

The historical data collected over the decades provides a crucial foundation for understanding the current status of fish assemblages in Rwanda's river systems. Continued research is essential to track changes in these populations, assess conservation needs, and implement effective management strategies for the protection of threatened fish species in the face of environmental changes.

CHAPTER VI: CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

The study focused on evaluating the effects of the Rusumo waterfall on fish communities within the Akagera River ecosystem. It aimed to determine variations in species richness, abundance, and diversity between upstream and downstream biotopes. The findings supported the first hypothesis, indicating significant differences between the two biotopes. Specifically, the study documented a total of 14 species, with downstream areas exhibiting a higher species richness of 14 compared to only 5 species identified upstream.

The results support that the Akagera River is a suitable habitat for four threatened species: *Labeo victorianus* (Ningu), *Haplochromis erythromaculatus*, *Cyprinus carpio*, and *Synodontis ruandae*. These species adapt in the conditions present in the river, which is crucial for their survival. The analysis revealed that while *Haplochromis erythromaculatus*, *Cyprinus carpio*, and *Synodontis ruandae* have a broader historical distribution across Rwanda, Labeo victorianus is predominantly restricted to only Akagera River, emphasizing its conservation importance.

The historical mapping indicates the need for targeted conservation efforts for the fish species, particularly for *Labeo victorianus*, which faces habitat restrictions. The study highlights the influence of the Rusumo waterfall as a potential barrier affecting fish migration and distribution patterns. Understanding these dynamics is critical for developing effective management strategies to protect and preserve these threatened fish species within the Akagera River system.

6.2. Recommendations

Further studies are needed to assess the impacts of local environmental conditions, and physico-chemical variables on the composition and structure of fish assemblages in the interface of waterfall. Also, other studies are needed on the assessment of the availability of recorded threatened fish species in their historical habitat waterbodies in Rwanda, to reassess their current presence or if there locally extinct to inform the fish conservation and water resources management. Thus, I recommend interventions from various stakeholders such as local fishermen, and fishery industries to be aware of fishing these endangered species. I call the Government of Rwanda through the Rwanda Environmental Management Authority to develop Akagera River and its catchment management plan that considers the conservation of threatened species, taking into account the sustainable management of freshwater hydrological networks, by considering the waterfall as a natural barrier for fish distribution.

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ANNEXES

Table 3: Occurrence of fish taxa at four sampled fishing stations of Akagera River, Kirehe district, October 2021 (*: Recorded, otherwise: Not recorded).

No	Taxa			Fishing station			
	Scientific Name	**Common Name**	**Family**	**Ruhuha**	**Gasenyi**	**Mitako**	**Karebezo**
1	*Bargrus docmac*	Semutundu	Bagridae			*	
2	*Haplochromis Ertythromaculatus*	Bulera haplo	Cichlidae		*		*
3	*Oreochromis niloticus*	Nile tilapia	Cichlidae	*	*	*	*
4	*Clarias gariepinus*	African sharptooth catfish	Clariidae	*	*	*	*
5	*Acapoeta tanganicae*	Mbaraga	Cyprinidae			*	
6	*Cyprinus Carpio*	Common Carpe	Cyprinidae		*		*
7	*Labeo Victorianus*	Ningu	Cyprinidae			*	*
8	*Mastecembelus frenatus*	Longtail spiny eel	Mastambelidae			*	
9	*Gnathonemus longibarbis*	Longnose stonebasher	Morymyriidae			*	*
10	*Petrocephalus catostoma*	Churchill	Morymyriidae			*	*
11	*Pollimyrus nigricans*	The dark stonebasher	Morymyriidae			*	*
12	*Protopterus aethiopicus*	African lungfish	Protopteridae	*	*	*	*
13	*Schilbe intermedius*	Silver butter catfish	Schilbeidae			*	*
14	*Synodontis ruandae*	Rwanda ruandae	Synodontidae			*	
	Total			**3**	**5**	**12**	**10**