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MASTER'S DISSERTATION

Bioassessment of water quality using benthic macroinvertebrates as bioindicators in Akagera River and wetland freshwater ecosystem.

by

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Submitted to the Department of Biology in partial fulfilment of the requirements for the degree of Master of Sciences in Biodiversity Conservation and Natural Resources Management

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Kigali, July 2023

Declaration

I, Yvonne Bigengimana, hereby declare that this thesis is the result of my original work except where otherwise cited and has never been submitted or published for any other degree at the University of Rwanda or any other institution.

Yvonne Bigengimana
Date: 12/11/2022

Certification

This is to certify that the work contained in the thesis entitled thesis "**Bioassessment of water quality using benthic macroinvertebrates as bioindicators in Akagera River and wetland freshwater ecosystem**" by Yvonne BIGENGIMANA in partial fulfillment of the requirements for the award of a master's degree in Biodiversity Conservation and Natural Resource Management at the University of Rwanda, College of Science and Technology has not been submitted or published elsewhere for a degree.

Date: 11 July 2023

Prof. Beth A. Kaplin
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Head of Department

Dedication

I would honor to dedicate this research to my parents in heaven, my uncle and aunt who raised me since my childhood and who tirelessly encourage me to move forward. To my brother and sister who always give me the courage to work hard. To my beautiful cousins who are always near to support me.

Acknowledgements

This research would not have been possible without the guidance and support of several individuals who valuably supported me in design and compilation of this project.

I thank very much my supervisors, Prof. Beth Kaplin and Dr Venuste Nsengimana for their valuable, professional, technical guidance and encouragement since the very early stage of this study.

Many thanks to the Center of Excellence in Biodiversity and Natural Resource Management for the capacity building through direct and indirect trainings as well as the support in field work logistics arrangement during this study.

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Finally, I would like to thank everyone who has contributed to the achievement of my master's studies in one way or another.

God bless you all.

Abstract

Every living organism needs fresh and clean water to survive. Particularly benthic macroinvertebrates are critically affected by changes in water quality. Despite their central role in hosting aquatic organisms and valuable services to human being, freshwater ecosystems are critically affected by habitat loss for aquatic macroinvertebrates and degradation mainly due to human activities such as agriculture and different sources of pollutants. The main purpose of this study is to assess the quality of Akagera river and wetland freshwater ecosystem using macroinvertebrates as bioindicators. I assessed the distribution and abundance of aquatic macroinvertebrates in the rivers that enter Akagera and Akagera river itself that forms the upper Akagera river and wetland freshwater ecosystem where this study was conducted. Data were collected within four main sites including two sites on Akanyaru and Nyabarongo rivers, and two sites on Akagera river and surrounding wetland for benthic macroinvertebrate assemblages and physico-chemical parameters including pH value, conductivity, temperature, and water speed. Riparian land use types were also recorded with focus on natural vegetation and agriculture. Collected macroinvertebrates were conserved in labeled containers with 96% ethanol solution and taken to the Zoological Collection located in the Center the Centre of Excellence in Biodiversity and Natural Resource Management and later identified to the family level using the identification keys. A total of 1920 specimens were collected, of which 1865 macroinvertebrates were identified and grouped into 5 classes, 10 orders, and 21 families. The results revealed that Akagera river and the surrounding wetland are dominated by macroinvertebrates that are highly tolerant to water pollution. The most commonly found families were Dytiscidae (55.07 %, N = 1027), Veliidae (14.64%, N=273), Belostomidae (9.71%, N=181), Grynidae (6.33%, N=116) and Psauridae (6.22%, N=116). A few individuals were found that are considered as moderately tolerate pollution. These are Hydranaenidae (0.05%, N=1), Nemouridae (0.05%, N=1), Paleonomidae (0.16%, N=3), Perlidae (0.11, N=2) and Naididae (0.21%, N=4). Regarding physico-chemical parameters, the recorded average pH value averagely varied between 6.7 and 7.8, the conductivity varied between 122.1 and 138.8 (µS/cm), water speed varied between 0.3 and 0.6m/s, while temperature varied between 21 and 22 ^{o}C. The land use within the sampled area is dominated by agriculture mainly cropland and sugarcane plantations on Nyabarongo and Akanyaru rivers. Natural vegetation was the most common land cover on Akanyaru river and some patches on Akagera river.

The upper Akagera river and wetland freshwater ecosystem seems to be polluted. The benthic macroinvertebrates found during this study indicated the dominance of highly tolerant macroinvertebrates and few of very low tolerant benthic macroinvertebrates.

Key words: benthic macroinvertebrates, bioindicators, water quality, Akagera river, Akagera wetland.

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1. Introduction

The availability of clean freshwater is essential for all living organisms (Ojija & Laizer, 2015). However, rivers and streams are globally accounted among the most endangered ecosystems that need regular evaluation and quality monitoring (Li et al., 2010). Many studies on fresh water quality monitoring have shown that the use of benthic macroinvertebrates as bioindicators provides a good approach to assess freshwater ecosystems status (Castro-López et al., 2019; Dusabe et al., 2019; Ojija & Laizer, 2015).

Biological indicators are defined as living organisms that are used to assess environmental health and biogeographic changes within the environment (Trishala, 2016). In other words, bioindicators are those organisms which have specific environmental tolerances, and whose presence or absence indicates specific environmental conditions (Johnson et al., 1993). Historically, freshwater quality monitoring using bioindicators goes far in 1800s (Mandaville, 1993), and it is still used as an important tool to detect and monitor positive or negative changes within water and wetland environments (Trishala, 2016).

Among the aquatic bioindicator communities, macroinvertebrates have been commonly used as bioindicators because they are easy to study, and their response to the environmental change can be clearly observed. For example, benthic bioindicators reflect the ecological conditions of aquatic ecosystem such as ecosystem health, level of pollution, habitat heterogeneity, food chain and water quality (Oliveira & Callisto, 2010). Assessment may consist of studying the abundance and distribution of macroinvertebrates and evaluate how they are affected by perturbations in the habitat. Moreover, the use of freshwater macroinvertebrates in water quality biomonitoring provides advantages because they are rich in species diversity, sedentary and long-lived which allows to determine the spatial and temporal changes, and hence provide evidence of habitat conditions and habitat change (Mandaville, 1993).

Land use is one of the major factors that affects biological quality of freshwater habitats and benthic invertebrates abundance and distribution (Carlson et al., 2013; Magbanua et al., 2016; Nerbonne & Vondracek, 2001). Riparian land use and anthropogenic disturbances such as conversion of land to agriculture, pollution, alteration of streams and increased input of nutrients contribute to the distraction of freshwater ecological integrity (Magbanua et al., 2016). Many studies (Berakhi et al., 2015; Carlson et al., 2013; Kim et al., 2016; Rios & Bailey, 2006; Theodoropoulos et al., 2015) confirmed the relationship between riparian land use types and macroinvertebrate assemblages, however the size of macroinvertebrates taxa within different land uses is linked to many biotic and abiotic factors (Castro-López et al., 2019; Dzinomwa & Ndagurwa, 2017).

The focus of this study is the upper Akagera river and wetland system in Rwanda, in central-eastern Africa. This study focuses on Akagera river and freshwater ecosystem which is a regional transboundary ecosystem that forms the border between Rwanda and Tanzania and it flows to lake Victoria (Wali, 2011) and Nile river (RWFA, 2019). The land-use of the Akagera basin is dominated by agriculture and grasslands and it is facing high pressures due to rapid economic development and changes in land cover and land use (Wali et al, 2011). This statement was later confirmed by Robel et al (2014) who, in their study recorded changes in Akagera basin land use over time and major changes noted include the conversion of rangeland into agricultural land for agriculture intensification which puts high pressure on Akagera river and wetland freshwater ecosystem (Berakhi et al., 2015; Fierro et al., 2017; Wronski et al., 2015).

2. Problem statement

Globally, water is a vital and limited resource which is under increasing demand from a growing number of users (MINIRENA, 2011) and healthy freshwater ecosystems are home to a wide range of aquatic species (Irfan & Alatawi, 2019). However, the increase in water demand leads not only to water users conflicts, but also to water resource and aquatic ecosystems degradation (Cox, 2008). The depletion of water resources and freshwater ecosystems, mainly caused by human activities such as high land degradation due to land cleaning for agriculture in catchment, is observable in Rwanda (MINIRENA, 2011), as well as in the whole east Africa region (Berakhi et al., 2015). Inadequate use of wetlands such as unsustainable agriculture, clay and sand mining, brick manufacturing, and lack of accurate data to understand long-term change and management of water resource is highlighted as the major challenge to sustainable management of water resource and associated aquatic ecosystems (MINIRENA, 2011). Aquatic ecosystems in Rwanda are also more vulnerable to water pollution caused by the use of chemical fertilizers and pesticides in the catchment areas (RNRA, 2012) and rapid economic development including urbanization, infrastructures construction and intensified agriculture (Uyizeye, 2020).

Water quality monitoring using biological indicators is commonly used in developed countries, but very limited in developing sub-Saharan countries, including Rwanda (Ojija & Laizer, 2015). Even though Rwanda has many freshwater ecosystems that play a key role in the development of the country and human livelihoods, they are classified among the most vulnerable ecosystems (Uyizeye, 2020). Moreover the situation in Rwanda is accelerated by high population increase and whose the high part depends on natural resource (GoR, 2011). The majority of the Rwandan population depends on freshwater ecosystem services for their daily lives and socio-economic development (REMA, 2009), and a regular freshwater quality monitoring should guide Integrated Water Resource Management (IWRM) decision making and sustainable use of freshwater resource.

The literature indicates that the use of macroinvertebrates as bioindicators of water quality is not new in Rwanda (ARCOS, 2016; Dusabe et al., 2019; Uyizeye, 2020). But the water quality assessments and monitoring conducted by the Rwanda Natural Resource Authority (RNRA), recently renamed Rwanda Water and Forestry Authority in 2011 (RNRA, 2012) and in 2019 (RWFA, 2019) currently called Rwanda Water Board, do not mention the use of benthic macroinvertebrates as bioindicators to monitor the biological quality of freshwater ecosystems. This may indicate that at national level, only physico-chemical parameters are examined to monitor water quality in Rwanda, while biological indicators are also considered as good and cheap tool to indicate and monitor the quality of freshwater ecosystem (Fierro et al., 2017). Collecting and sharing adequate data is key to sustainable management of freshwater ecosystems in Rwanda, however, apart from Dusabe et al. (2019), who conducted biological water quality assessment using macroinvertebrates in Muvumba river and Uyizeye (2020) who developed an Odonate-Based Index for Monitoring Freshwater Ecosystems in Rwanda, the literature do not reveal much information on freshwater quality monitoring using benthic macroinvertebrates, particularly on Akagera river and wetland.

Being a transboundary ecosystem, Akagera river ecosystem plays a regional conservation role. However the Akagera river is highly affected by land use impacts (Berakhi et al., 2015; Ndayisaba et al., 2017) and its catchment management plan is not yet developed (RWB, 2018), which may accelerate unproper land use within the catchment area. Moreover, there is a gap in information about the monitoring of Akagera freshwater ecosystem using macroinvertebrates as bioindicators.

In addition to lack of data on macroinvertebrates within Akagera river and wetland, the ecosystem lacks regular biological water quality assessments and monitoring.

To contribute to sustainable management and conservation of Akagera river and wetland freshwater ecosystem, and monitoring of biological quality of habitats within Akagera river and wetland, the purpose of this study is to provide an updated information about the benthic macroinvertebrates that exist within upper Akagera river and wetland ecosystem, and the impacts of land use on macroinvertebrate assemblages' abundance and distribution. This study was conducted with the intention to also produce a baseline tool that would serve to identify and monitor environmental stressors in Akagera river and wetland freshwater ecosystem.

3. Objectives

Main Goal

The main goal of this study is to contribute to the improved monitoring of freshwater ecosystem quality using benthic macroinvertebrates as bioindicators in Rwanda.

Specific objectives seek to:

1) Assess the abundance and distribution of freshwater benthic macroinvertebrates in Akagera river and wetland freshwater ecosystem.
2) Determine the status of the Akagera freshwater ecosystem quality using benthic macroinvertebrates and physico-chemical parameters.
3) Examine relationship between the riparian land use types and benthic macroinvertebrates abundance and distribution.

Research questions

i) What are benthic macroinvertebrate assemblages found in Akagera river and wetland freshwater ecosystem?

ii) What do benthic macroinvertebrates abundance and distribution indicate about the status of Akagera river and wetland freshwater ecosystem quality?

iii) What is the relationship between the riparian land use types along Akagera river and abundance and distribution of macroinvertebrates?

4. Methodology

4.1. Study area

Part of the Nile Basin and rich freshwater aquatic ecosystem, Akagera river is formed by the confluence of Nyabarongo and Akanyaru rivers and it is the largest river that drain into Lake Victoria. Akagera river crosses the eastern part of Rwanda from Bugesera district to Nyagatare district. Akanyaru river forms the border between Rwanda and Tanzania (Wali, 2011). The total surface area of Akagera catchment is 13,624 km2 including 6,982 km² for the upper catchment and 6,642 km² for the lower catchment with 4,288 km² located in Rwanda (RWB, 2020). This study was conducted within the upper Akagera river and wetland freshwater ecosystem mainly at the confluence of Nyabarongo and Akanyaru rivers in Bugesera, Kamonyi and Kicukiro districts. In Bugesera samples were taken in Ntarama sector, Kibungo and Kanzenze Cells. On Kamonyi side samples were taken in Mugina sector, Nteko Cell. On Kicukiro side samples were collected in Gahanga sector, Murinja Cell.

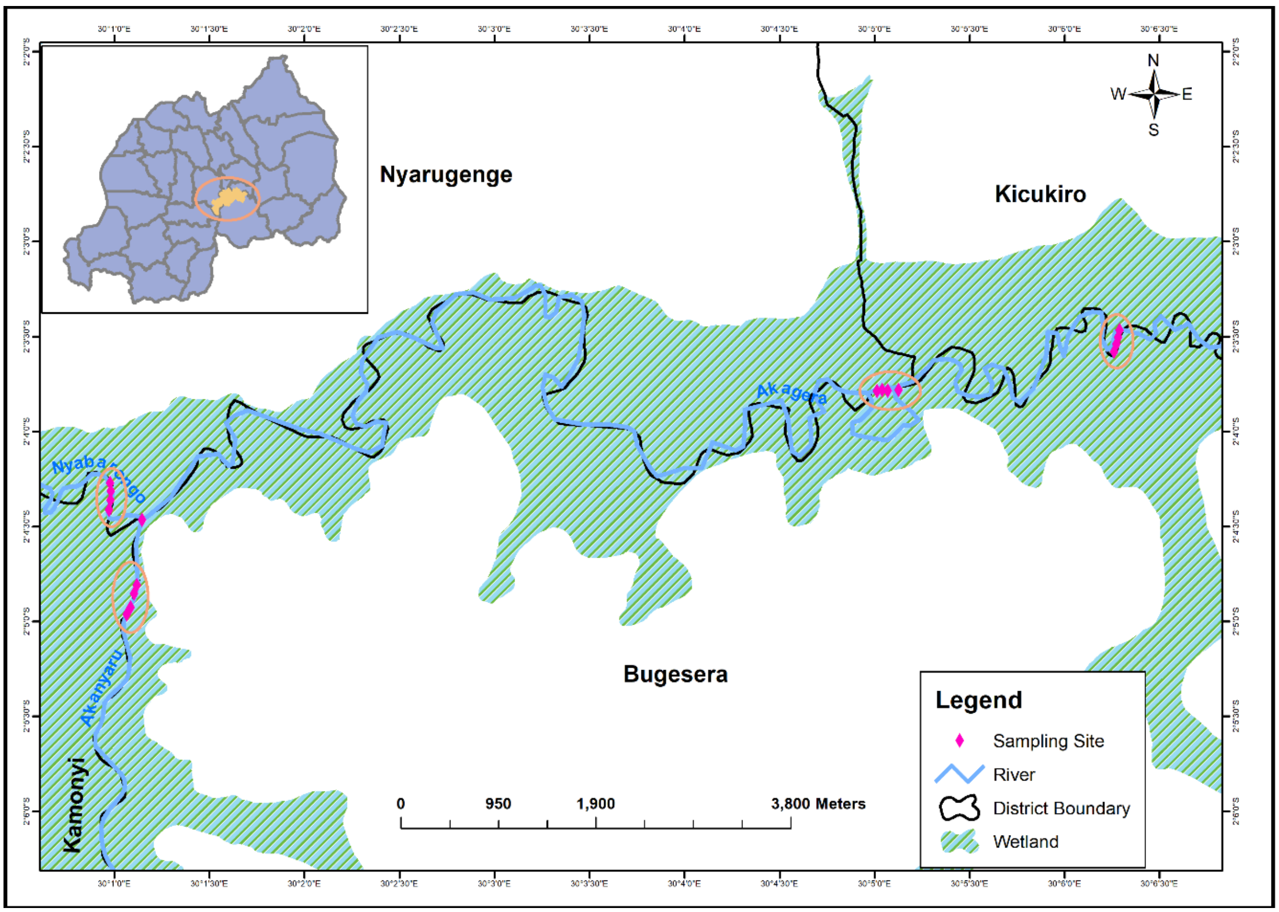


FIGURE 1: MAP SHOWING THE SAMPLED SITES ALONG AKAGERA RIVER AND WETLAND IN EASTERN RWANDA

Four sampling sites (Figure 1) were selected, taking into consideration various land use types along the river flows and surrounding wetland, with focus on agricultural land and natural vegetation in riparian zone. One sampling site was selected on Akanyaru river side, one sampling site on Nyabarongo river side, and two sampling sites on Akagera river. Four transects of 150 m each were set along the selected sampling sites.

4.2. Data collection

Primary data collection of macroinvertebrate assemblages and documentation of land use around the Akanyaru, Nyabarongo and Akagera rivers and wetland ecosystem were collected directly in the field in the selected sampling sites. Secondary data were collected through the desk review of publications and articles similar to this study to complete field data and macroinvertebrates identification. In the field, data were collected in key rivers (source) and wetland of Akagera river basin system, in its upper part located between the districts of Bugesera, Kamonyi and Kicukiro districts. Four sites were sampled using various techniques ranging from direct point (1 m^2) counts and opportunistic sampling along the transects with standard time period (Kualiti et al., 2015). Four transects, of 150 m each, in total were set and sampled along Akanyaru river (1 transect), Nyabarongo river (1 transect) and Akagera river (2 transects) to quantify benthic macroinvertebrate communities, and their habitats status. The data were used to measure macroinvertebrate assemblage occurrence, abundance, and distribution in linkage to water quality.

Macroinvertebrate sampling

Macroinvertebrate samples were collected at 16 sampling sub-sites or points. At each transect macroinvertebrate sampling points were placed directly to the river water ways or extended to 10 meters (m) from the river edge, towards riparian wetland area (uplands) perpendicularly to water way depending on accessibility. Four sampling points of $1m^2$ each, separated by 50 m, were set along each transect where macroinvertebrates were collected using a net. For each transect, the first point was chosen randomly, and the following points were subsequently set in regular interval of 50 m. Each sampling site was selected based on habitat type with focus on natural vegetation and agriculture.

Macroinvertebrate samples were taken using a kick-net of 0.25 millimeters mesh size, by disturbing water and the substrates for a 5-minute period at each sampling point (Correa-Araneda et al., 2021).

Where the flowing water was accessible the net with a long holder was placed against the disturbed flow of water by shuffling the net at least 10 times within 30 seconds (Siziba et al., 2018).

Collected macroinvertebrates were gathered in a plastic bucket, cleaned, sorted and conserved in a labeled container with 96% ethanol solution (Magbanua et al., 2016). Collected individuals were taken to Zoological Collections Unit at the Center of Excellence in Biodiversity and Natural Resource Management for identification. The identification was done up to family level using morphological features. The sensitivity to water pollution was assessed with reference to the sensitivity scales derived from the tolerances to water pollution as used in the South African Scoring System, version 5-SASS5 scoring system (Dickens & Graham, 2002) that classifies benthic invertebrates into categories based on their sensitivity to water pollution. As it was more clarified in (Gerber A., 2002), the SASS5 classifies benthic macroinvertebrates in three categories including 1-5 Highly tolerant to pollution; 6-10 Moderately tolerant to pollution and 11-15 Very low tolerance to pollution (Figure 2). Using the SASS5 scoring system guide (Gerber, 2002), collected macroinvertebrates were classified into water pollution sensitivity using the SASS5 scoring system guide, and luckily, all identified families for this study were found among the families already classified by the SASS5.

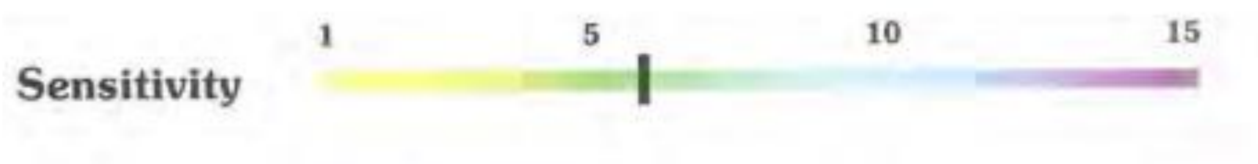


FIGURE 2: SASS5 BENTHIC MACROINVERTEBRATES SENSITIVITY CLASSIFICATION SYSTEM (GERBER, 2002).

Physico-chemical data collection

During this study physico-chemical parameters including pH value, conductivity, temperature, and water speed were measured and recorded on Akanyaru river, Nyabarongo and Akagera river at the sites where macroinvertebrates were recorded. A pH meter was used to measure pH, a conductometer to measure conductivity and thermometer to measure temperature. Water speed was measured directly on the river by putting a light leave on flowing water, on a distance of 1m and calculate the time used to run 1m. I also used findings from previously published research reports from the study site to complete the recorded physico-chemical data standards for freshwater ecosystems.

Land use data collection

The main idea for this study was to set samples within natural vegetation and agriculture lands within all sampled areas to assess the effects of land use on benthic macroinvertebrate abundance and distribution. But on Akanyaru side, the river was surrounded by natural vegetation only in the sampling area, except some patches that were being cleared by local communities for agriculture, while on the Nyabarongo side there was no natural vegetation at all within the sampled area that is surrounded by sugarcane plantations. To keep the study idea, two sampling sites within natural vegetation were set on Akanyaru river (1) and Akagera (1) and two sampling sites within agriculture lands on Nyabarongo (1) and Akagera (1). The land cover and land use were noted through direct observation and record of land use types within the sampled sites with limit to agriculture and natural vegetation lands in the riparian area. The land use type was the key parameter that helped to fix sampling points for both macroinvertebrates and physico-chemical parameters. Along the transect, on the river way, sampling points were set either directly on the river or within 10 m in the surrounding wetland from the river depending on accessibility and vegetation composition with focus on *Cyperus papyrus* and *Polygonum sp* for the land covered by natural vegetation. For the agriculture lands, sampling points were set mostly directly on the river edge because there were no wetlands in surrounding areas that were purely converted to agriculture dominated with major plantations of sugarcane, beans and vegetables.

Data analysis

The collected macroinvertebrate individuals were analyzed to the family level. In addition to the laboratory analysis, relative abundance was calculated for families that represent at least 1% of all recorded individuals. Statistical analysis using R-Studio software version 3.6. was used to check the distribution of macroinvertebrates among the sampled areas. The normality was tested for six families with significance representation (3% of all individuals) using Shapiro-Wilk and Kruskal-Wallis tests were used when non normally distributed (Ostertagová et al., 2014). Where the variables were normally distributed around the mean, ANOVA was used to check the distribution among Akagera, Akanyaru and Nyabarongo. Furthermore, the Principal Component Analysis (PCA) was used to analyze macroinvertebrates abundance and distribution within the sampled areas. The analyzed abundance and distribution of benthic macroinvertebrates were linked to the recorded land physico-chemical parameters and land use type to check the relationship between macroinvertebrates abundance and surrounding environment.

5. Results

A total of 1920 individuals of macroinvertebrate distributed into 5 classes, 10 orders, and 21 families were recorded, including 55 individuals that were not identified due to lack of identification key and short time for this study to consult experts. The analysis was done on 1865 individuals that were identified to family level (Table 1).

Table 1: Summary of recorded macroinvertebrates within sampled sites.

No	Class	Order	No_Families	Family Names	Abundance (Absolute)
1	Arachnida	Araneae	2	Pisauridae	116
				Pholcidae	13
2	Gastropoda	Basommatophora	1	Planorbidae	2
3	Insecta	Coleoptera	4	Hydraenidae	1
				Sphaeriusidae	31
				Gyrinidae	118
				Dytiscidae	1027
4	Malacostraca	Decapoda	2	Palaemonidae	3
				Potamonautidae	4
5	Insecta	Diptera	1	Chironomidae	14
6	Insecta	Ephemeroptera	1	Baetidae	17
7	Insecta	Hemiptera	5	Gerridae	22
				Belostomatidae	181
				Naucoridae	2
				Veliidae	273
				Nepidae,	5
8	Insecta	Odonata	2	Libellulidae	13
				Coenagrionidae	16
9	Insecta	Plecoptera	2	Nemouridae	1

				Perlidae	2
10	Clitellata	Haplotaxida	1	Naididae	4

The families of Dytiscidae (55.07 %, N = 1027), Veliidae (14.64%, N=273), Belostomidae (9.71%, N=181), Grynidae (6.33%, N=116) and Psauridae (6.22%, N=116) were dominant, while the families of Hydranaenidae (0.05%, N=1), Nemouridae (0.05%, N=1), Paleonomidae (0.16%, N=3), Perlidae (0.11, N=2) and Naididae (0.21%, N=4) were less represented with few individuals. Based on the SASS5 classification and scoring system, the recorded individuals dominated by families that are highly tolerant to water pollution. Among the 21 identified families, 11 families fell in the highly tolerant range (1-5), 7 families fell in the range of moderately tolerant scale (6-10) while the 3 remaining families fell in the range of very low tolerant (11-15) (Figure 3).

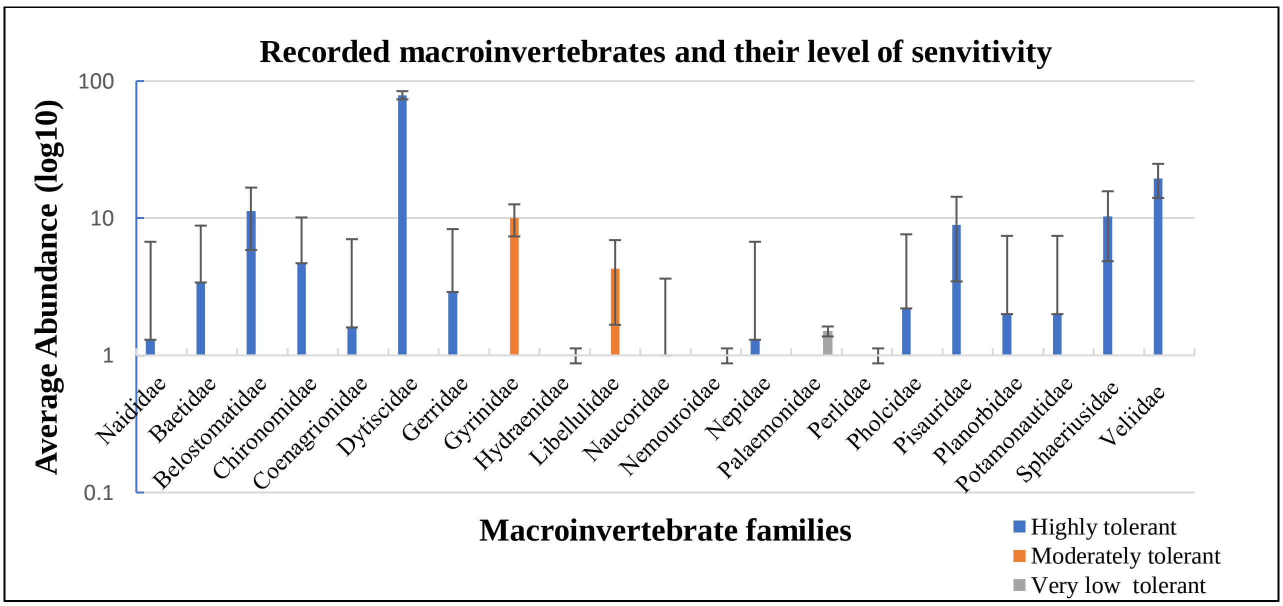


FIGURE 3: RECORDED BENTHIC MACROINVERTEBRATES AND THEIR LEVEL OF SENSITIVITY IN THE AKAGERA RIVER AND WETLANDS, RWANDA

5.1.Macroinvertebrates abundance and distribution

The Akanyaru river side composed of natural vegetation showed a high number of macroinvertebrates while the lowest abundance was recorded in Nyabarongo river side (Figure 4).

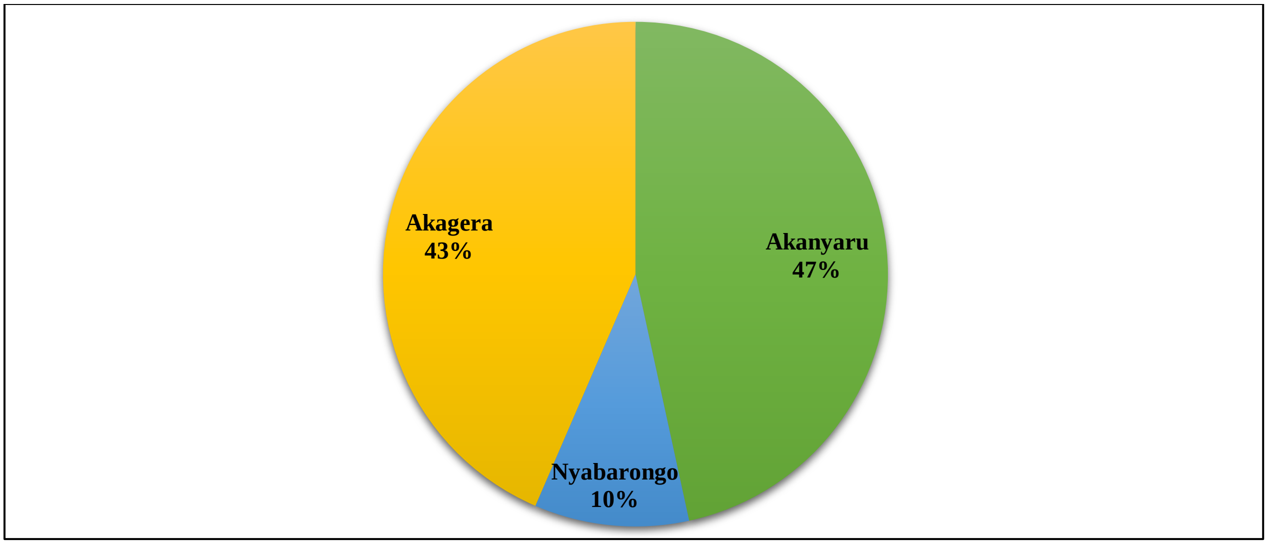


FIGURE 4: ABUNDANCE OF MACROINVERTEBRATES WITHIN SAMPLED SITES.

Among 21 families recorded, 6 families that represent at least 3% of all recorded individual macroinvertebrates were considered during the analysis of family distribution and abundance. The statistical analysis showed that macroinvertebrates among the sites were normally distributed around the mean in Belostomidae family (F=4.1208, p-value=0.05364; Figure 5). However not all families were evenly distributed at the sampled sites. The results showed that there was a significant difference in the distribution of Dytiscidae (p-value = 0.02; Figure 6); Gyrinidae (p-value = 0.041; Figure 7); Pisauridae (p-value = 0.007758; Figure 8); Sphaeriusidae (p-value = 0.02792; Figure 9) and Viliidae (p-value = 0.2603**;** Figure 10) among the sites.

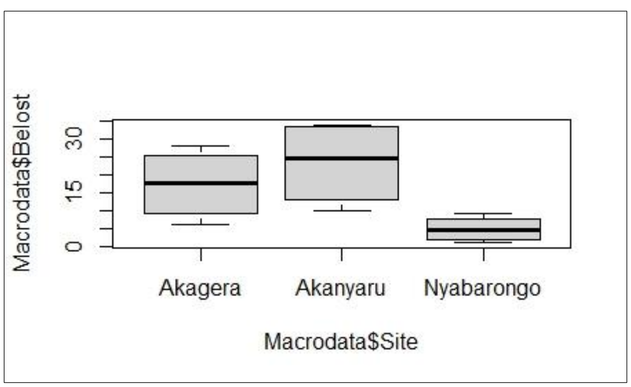


FIGURE 5: BELOSTOMIDAE DISTRIBUTION AMONG SITES AMONG SITES

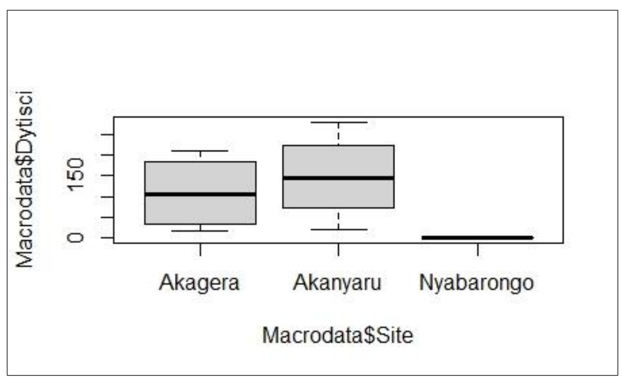
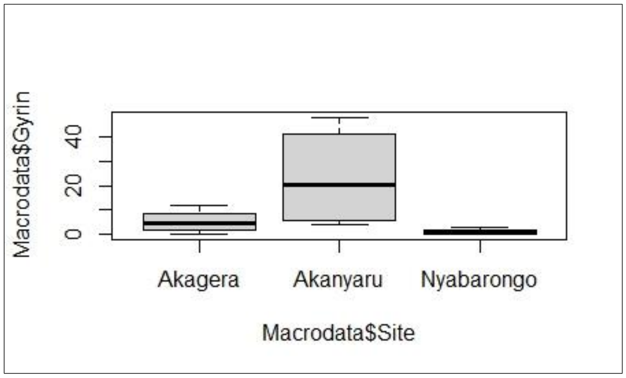


FIGURE 6: DYTISCIDAE DISTRIBUTION



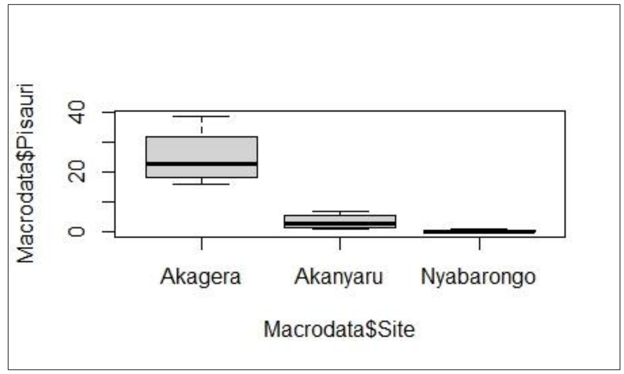
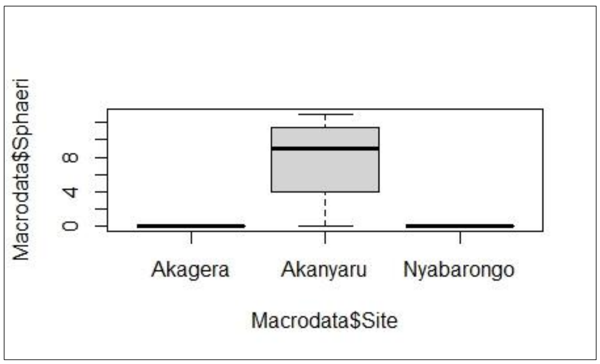


FIGURE 7: GYRINIDAE DISTRIBUTION AMONG SITES **FIGURE 8: PISAURIDAE DISTRIBUTION AMONG SITES**



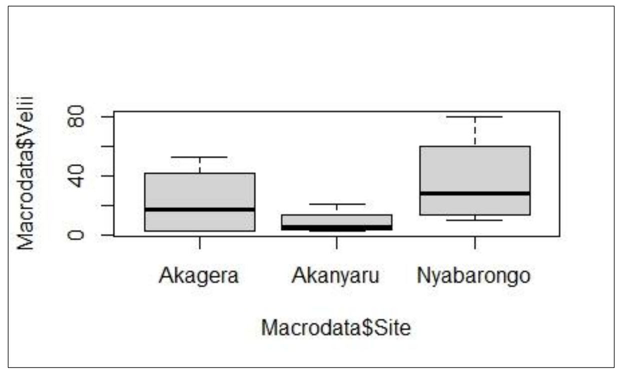


FIGURE 9: SPHAERIDAE DISTRIBUTION AMONG SITES **FIGURE 10: VELIIDAE DISTRIBUTION AMONG SITES**

The figures above show the differences among macroinvertebrate distribution and abundance within the sampled sites. For example, looking at Figures 6, 7 and 9, the Akanyaru river side showed a high abundance of macroinvertebrates of the families of Belostomidae, Dytiscidae, Gyrinidae and Sphaeriusidae. The family of Veliidae was most found on Nyabarongo and Akagera rivers, with less representation on Akanyaru river (Figure 10). The families of Belostidae, Dytiscidae, Pisauridae and Veliidae were most abundant on Akagera river side (Figures, 5, 6, and 10) contrary to the families of Gyrinidae and Sphaeriusidae that were less found on Akagera river site (Figures 7 and 9).

5.2. Physico-Chemical parameters

Physico-chemical parameters measured during this study include the water speed, temperature, pH value and conductivity. The calculated means of recorded physico-chemical parameters indicated the lowest water speed on Akanyaru river side (0.3m/s) while the water speed in Nybarongo side and Akagera river varied between 0.6 and 0.7 (m/s). The temperature varied between 21 and 22^{0}C.

The conductivity varied between 119.1 µS/cm on Akanyaru river side with natural vegetation and 138.2 µS/cm within sugar agriculture areas. Regarding the pH among the sampled sites, the lowest pH (6.7) was recorded on Akanyaru river side while the highest pH was recorded in Nyabarongo (7.8) in sugarcane plantation and in Akagera (7.8) cropland sites (Figure 11).

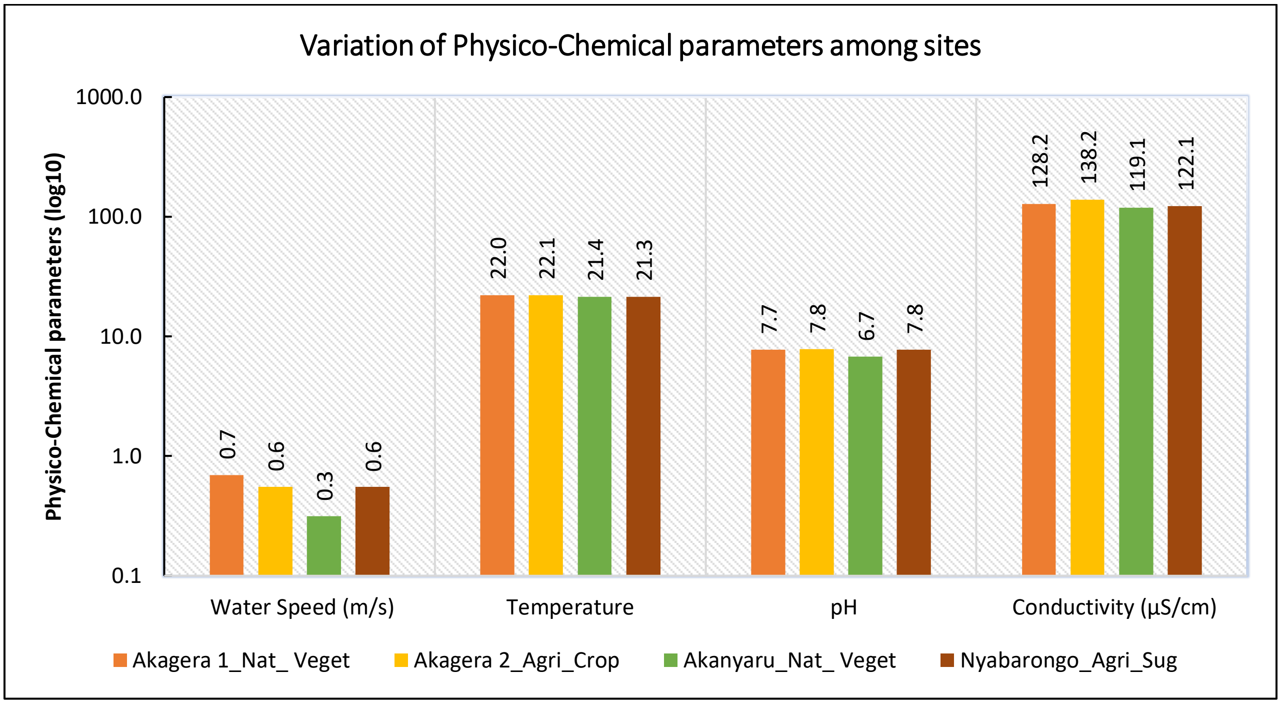


FIGURE 11: AVERAGES OF RECORDED PHYSICO-CHEMICAL PARAMETERS AMONG SITES.

5.3. Land use

Land use identification was directly recorded at each sampling point considering natural vegetation and agricultural land. The Akagera river in the upper areas where this study was conducted is dominated by agriculture including cropland and sugarcane plantations and some patches of natural vegetation dominated by Papyrus and Polygonum vegetation. Akanyaru river side still has natural vegetation dominated by papyrus though during this study many areas around the river were being cleared for crop cultivation, mainly beans and vegetables. No site with natural vegetation was found on Nyabarongo river side among the sampled sites during this study.

Relative abundance per land use

The Dytiscidae family was recorded with a high abundance particularly in Akanyaru where the lowest average water speed (0.3m/s) and conductivity (119.1 µS/cm) were recorded, and the average of the recorded pH value is around 6.7 which is close to neutral environment in terms of acidity and basicity. The same family was abundant within Akagera sites with natural vegetation as well as cultivated areas where the average pH values indicated a basic environment 7.7 for natural vegetation site and 7.8 for cultivated site. This suggests that being a highly tolerant family (Figure 3), the Dytiscidae family individuals can adapt to both acidic and basic environments. On the other hand, the family of Veliidae, which is also a highly tolerant family (Figure 3), was abundant around the sugarcane plantations of Nyabarongo where the average of the recorded pH value (7.8) indicates a basic environment. Pisauridae were also abundant in waters adjacent to cropland areas (Figure 12).

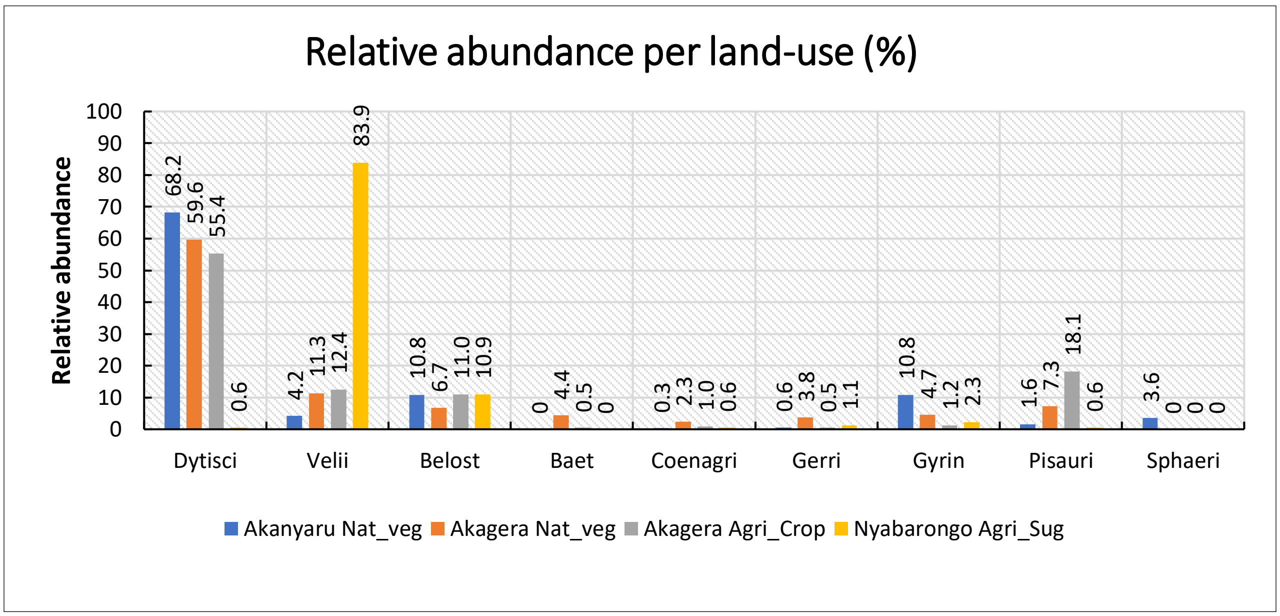
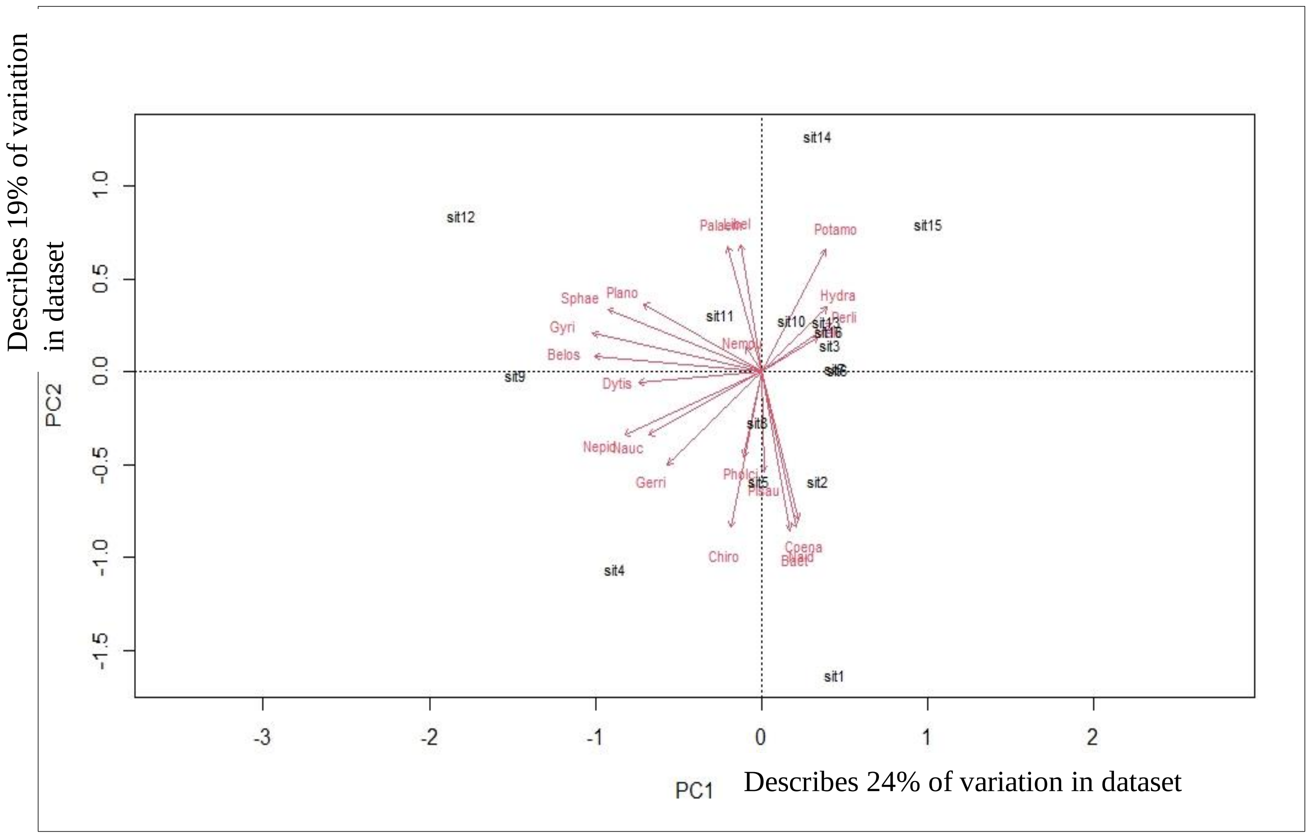


FIGURE 12: MACROINVERTEBRATES RELATIVE ABUNDANCE AMONG SITES.

The Principal Component Analysis (PCA) included all 16 sampled points (Sit) within 4 sampled sites. The PCA analysis showed the similarities in the distribution of the families Hydraenidae, Perlidae and Potamonautidae within the sites of Akegera natural vegetation (Sit3), Akanyaru natural vegetation (Sit10), and Nyabarongo (Sit13 and Sit16). The distribution of the families of Coenagrionidae and Baetidae was likely to be more similar within Akagera natural vegetation (Sit1 and Sit2) compared to other sites. The families of Belostomatidae and Dytiscidae were more similarly distributed in Akanyaru natural vegetation site (Sit12). The family of Pisauridae is more similarly distributed abundant within Akagera agriculture (Sit5 and Sit8) than other sites. On Nyabarongo site, particularly on Sit13, the family of Veliidae was more abundant than any other sampled site. This family was less abundant in sites with natural vegetation on Akanyaru (Sit11 and Sit12) and Akagera (Sit2 and Sit4) are not likely to be abundant in Velliidae (Figure 13).

FIGURE 13: PRINCIPAL COMPONENT ANALYSIS (PCA) FOR MACROINVERTEBRATES RELATIVE ABUNDANCE AMONG SAMPLED SITES.



6. Discussion

This study was conducted with the main objective to assess the quality of Akagera river and surrounding wetland freshwater ecosystem using benthic macroinvertebrates as bioindicators. The sampling area included the Akanyaru and Nyabarongo rivers, which are the main sources of Akagera river. The results of this study show that macroinvertebrates were more abundant in the Akanyaru river that may lead to believe that Akanyaru river hosts more benthic macroinvertebrates found in the Upper Akagera river and wetland ecosystem.

From the direct observation in the field, and based on the work of Berakhi et al. (2015), the difference in benthic macroinvertebrate abundance and distribution among the sampled sites can be linked directly to human activities mainly the conversion of natural vegetation into agricultural land around Akagera river. The low number of individuals recorded on Nyabarongo side is probably explained by the impact of agriculture activities and the use of chemicals in the adjacent lands. A high abundance of benthic macroinvertebrates was recorded on the Akanyaru river side which still has natural vegetation in the riparian areas and with slow water speed.

Physical chemical parameters also play an important role in the abundance and the distribution of macroinvertebrates. Families such as Veliidae and Pisauridae were more abundant in waters adjacent to cultivated areas of Nyabarongo and Akagera where the highest pH values were recorded, and which may be linked to the chemical run off from adjacent cultivated fields. Generally the results of this study, particularly on conductivity and pH value showed compliance with international standards 2500 µS/cm for conductivity, 5.5-9.5 for pH value as it was stated by the Water for Growth Rwanda (WGR) during the study conducted on Rwanda water quality using physico-chemical parameters for the key rivers of Rwanda, including Akagera river (WGR, 2018). However, there is need to pay attention to the high pH value of around 8 found in Nyabarongo and Akagera rivers particularly on sites with agriculture. On Akanyaru river side with natural vegetation, the recorded pH value varied between 6.5 and 6.9 which is reasonable for a freshwater habitat, and this may show Akanyaru river as a healthy ecosystem compared to the cultivated sites of Nyabarongo and Akagera. The recorded conductivity complies with the standards; it varies between 115.7 µS/cm and 138.2 µS/cm in all sampled sites. The averages of recorded conductivity on Akanyaru, Nybarongo and

Akagera rivers comply with the standards for freshwater ecosystems, but among the sampled sites, a low conductivity was recorded on Akanyaru side.

Regarding the sensitivity to water pollution, the recorded benthic macroinvertebrates show the pollution of the Akagera river and wetland freshwater ecosystem, which is indicated by the dominance of highly tolerant families, low number of moderately tolerant families and almost complete absence of very low tolerant benthic macroinvertebrates in the sampled sites. This indicates poor water quality of the Akagera river and wetland ecosystem as a freshwater ecosystem. The same issue was reported on the other rivers of the eastern part of Rwanda (Dusabe et al., 2019).

In addition, water current is one of the factors that, ecologically, regulates the distribution of macroinvertebrates (Qazi A. Hussain, 2012). This may explain the high number of macroinvertebrates recorded on Akanyaru river side where a low water speed (0.3m/s) was recorded compared to Nyabarongo (0.6 m/s) and Akagera (0.7m/s). Moreover, the high water speed may explain the high number of Veliidae individuals recorded on Nyabarongo river side, because Veliidae have a small body and legs adapted to running on the surface of water (Gerber, 2002).

In addition to the above-discussed physico-chemical parameters, this study found that land use type affects importantly the distribution of macroinvertebrates as well as the quality of water. This study focused on natural vegetation and agriculture lands as the main land use types observed directly around the sampled sites. Akanyaru river still has natural vegetation though during this study many areas around that river were being cleared for agriculture. This can be linked, again, to the high number of individuals recorded in Akanyaru river side and the high presence of Belostomatidae macroinvertebrates that normally prefer to live at the bottom and quiet areas of the stream.

On Nyabarongo side, no site with natural vegetation was found among the sampled sites during this study. The river is rather surrounded by big areas of sugarcane plantations and croplands which may explain its shortage in macroinvertebrate assemblages due to the riverbank degradation and heavy erosion in the riparian area. Also, the high pH value recorded may result from the direct flow of chemicals used in vegetables and sugarcane plantations, and the lack of the buffer zone around the river may enhance the filtration of some minerals. Due to land degradation and heavy erosion in riparian areas, it is reasonable to expect the dominance of the Veliidae family in Nyabarongo because they are adapted to live on the surface of water as their main habitat. For the Akagera river, the upper part at the confluence of Akanyaru and Nyabarongo is dominated by sugarcane plantations and croplands with no buffer zone or any other measure of riparian zone protection. Some patches of natural vegetation were found down near the Gahanga bridge. Looking at the relative abundance within the sampled sites with Akagera, only the Dytiscidae family was dominant in natural vegetation while the Veliidae, Belostomatidae and Pisauridae families were more dominant in cultivated areas than natural vegetation.

7. Conclusion and recommendations

The Akagera river and wetland freshwater ecosystem is dominated by benthic macroinvertebrates that are highly tolerant to water pollution. Only four moderately tolerant families (Gyrinidae, Hydraenidae, Naucoridae and Pholcidea) and one very sensitive family (Perlidea) were recorded in Akagera river and wetland which suggests that the Akagera river and wetland freshwater ecosystem is ecologically poor in terms of water quality. Akanyaru river seems to host more of the benthic macroinvertebrates found in upper Akagera river and wetland freshwater ecosystem. Physico-chemical parameters of Akagera river complies with international freshwater ecosystem standards, but pH value is tending to the limit. The Akagera river and wetland ecosystem is highly threatened by habitat degradation due mainly to agriculture activities and heavy soil erosion in the riparian areas. The lack of clear buffer zone around the river worsens the situation.

As Akagera river and wetland ecosystem is one of the main aquatic ecosystems in Rwanda and a transboundary ecosystem, I recommend the Government of Rwanda through the Ministry of Environment to increase efforts in protection and conservation of Akagera river source. I also recommend the reinforcement of buffer zone management, because if we continue with the business as usual, we will not only lose the river ecosystem health and ecological functions, but also people's lives. Furthermore, the catchment management plans were developed for key rivers in Rwanda, but I could not find any catchment management plan for the upper Akagera river, and I recommend its development and implementation urgently. Regular monitoring of water quality using macroinvertebrates should be done to ensure biological quality of Akagera river and wetland freshwater ecosystem as well as sustainable conservation of macroinvertebrate species.

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Annexe 1: Recorded macroinvertebrates per site

No	Family	Number of individuals per site			Sensitivity
		Akanyaru	**Nyabarongo**	**Akagera**	
		1 transect	**1 transect**	**2 transects**	
1	Veliidae	36	146	91	Highly Tolerant
2	Baetidae	0	0	17	Highly Tolerant
3	Belostomatidae	93	19	69	Highly Tolerant
4	Chironomidae	0	0	14	Highly Tolerant
5	Coenagrionidae	3	1	12	Highly Tolerant
6	Dytiscidae	589	1	437	Highly Tolerant
7	Gerridae	5	2	15	Highly Tolerant
8	Gyrinidae	93	4	20	Moderately Tolerant
9	Hydraenidae	0	0	1	Moderately Tolerant
10	Libellulidae	6	7	0	Moderately Tolerant
11	Naucoridae	1	0	1	Moderately Tolerant
12	Nemouridae	1	0	0	Very low tolerance
13	Nepidae	2	0	3	Highly Tolerant
14	Palaemonidae	1	2	0	Very low tolerance
15	Perlidae	0	1	1	Very low tolerance
16	Pholcidae	2	1	10	Moderately Tolerant
17	Pisauridae	14	1	101	Highly Tolerant
18	Planorbidae	2	0	0	Highly Tolerant
19	Potamonautidae	0	0	4	Moderately Tolerant
20	Sphaeriusidae	31	0	0	Highly Tolerant
21	Naididae	4	0	0	Moderately Tolerant
22	Unidentified	11	5	39	N/A
	Total	**894**	**190**	**835**	

Annex 2: Some pictures taken during field data collection and Analysis.

FIGURE 14: THE JUNCTION OF AKANYARU AND NYABARONGO RIVERS

FIGURE 15: AKANYARU RIVER SIDE (LEFT) AND NYABARONGO RIVER SIDE (RIGHT)

FIGURE 16: FIELD DATA COLLECTION

FIGURE 17: DATA ANALYSIS IN THE LABORATORY