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EVALUATING IRRIGATION EFFECTS ON WETLAND HEALTH USING BENTHIC MACROINVERTEBRATE INDICATORS IN DROUGHT-PRONE AREA OF KAYONZA DISTRICT, RWANDA

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Sciences in NATURAL RESOURCES MANAGEMENT AND BIODIVERSITY CONSERVATION

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DECLARATION

I declare that the thesis called **“EVALUATING IRRIGATION EFFECT ON WETLAND HEALTH USING BENTHIC MACROINVERTEBRATES INDICATORS IN DROUGHT-PRONE AREA OF KAYONZA DISTRICT, RWANDA”** is my original research.

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DEDICACE

I dedicate this thesis:

To my Almighty God,

To my regretted parents,

To my beloved husband,

To my beloved son and daughters,

To my brothers and sisters,

To all scientists contributing to environmental protection and biodiversity conservation.

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This research would not be successful without intellectual, financial, and moral support as well as material on behalf of different people to whom we return a right tribute of homage and recognition.

I firstly respectfully thank Prof. Beth A. Kaplin, the pillar and root of this research who ensured supervision of this study from the beginning to the end with valuable guidance and relevance of scientific spirit to trigger my critical thinking to achieve these research goals despite her multiple responsibilities. For that, she finds here expression of my deep gratitude.

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Sincerely thanks,

MUKASANGWA Aloysie

ABSTRACT

Freshwater ecosystems are multi-functional ecosystems, and whole communities are dependent upon their productivity and hydrological benefits. In Rwanda, the response of farmers to the pressure on land and the long dry season associated with a decline in productivity has been to expand their agricultural activities into these fragile wetlands. Human activities that demand wetland management, water diversion and damming, land alteration and use of agrochemicals, impose negative impacts not only on wetland value but also on the whole ecosystems particularly organisms depending on wetlands via stream change. With 11% of the total land of the country, Rwanda's wetlands are the fastest lost and degraded compared to any other ecosystems. In Rwanda, irrigation systems are being implemented to address drought caused by climate change, aiming to reduce dependency on rain-fed agriculture, particularly in the Eastern Province. However, the effects of irrigation on wetlands are still not well documented; we aimed to evaluate the effect of irrigation on wetland health using benthic macroinvertebrates. With the spot sampling method, we identified the BMI community and indicator species of wetland health and we identified potential interaction between benthic macroinvertebrates and wetland use practices; we developed a baseline for monitoring wetland health based on indicator species in the study areas. As BMI are sedentary organisms sensitive to threats to wetland ecosystems, their assemblage gives information on biotic and abiotic factors interacting with them. This provides ecological information on the wetland ecosystem health upstream, downstream and within the dam differently during low and high precipitation. Precipitation periods combined with irrigation activities influence the distribution of pollutants from human activities, and this in turn impacts BMI assemblages in streams, especially related to adjacent land use practices. This was observed in areas dominated by agriculture where BMI tolerating agrochemical pollution was abundant while BMI affected by that pollution was found in areas of less agriculture and livestock activities. EPT sensitive group of BMI was mostly from upstreams of areas with less agricultural activities while tolerant were highly recorded downstream in areas dominated by agriculture. The poorer the stream health, fewer sensitive species were found during the sampling and the presence of numerous individuals of highly tolerant organisms is expected. There are opportunities to improve the management of irrigation practices, such as avoiding cement-lined water channels, restoring riparian zones, raising skills in the use of agrochemicals and reducing polluting run-off into wetlands; that support healthy functioning ecosystems. BMI are shown to be effective indicators of water quality in this wetland system.

Keywords: Benthic macroinvertebrates, biological indicators, EPT, and stream.

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ABBREVIATION

BMI: Benthic macroinvertebrates

KIIWP: Kayonza Irrigation and Integrated Watershed Management Project

CoEB: Center of Excellence in Biodiversity and Natural Resource Management

RAB: Rwanda Agriculture and Animal Resources Development Board

MINAGRI: The Ministry of Agriculture and Animal Resources

KMP (1, 2…): Kageyo macroinvertebrates plot (1, 2, 3, 4)

GMP (1, 2…): Gatindo macroinvertebrates plot (1, 2, 3, 4, 5)

MMP (1, 2…): Mucucu macroinvertebrates plot (1, 2, 3, 4, 5)

DO: Dissolved oxygen (mg/l)

TDS: Total dissolved solid (mg/l)

T^o: Temperature (^{o}C)

PH: Potential of hydrogen

^{o}C: Celsius degree

NTU: Nephelometric turbidity units

T: Trichoptera

E: Ephemeroptera

P: Plecoptera

D: Diptera

CHAPTER I. INTRODUCTION

1.1. Background of the study

Anthropogenic activities that require wetland management and water diversion such as agriculture, dams, and irrigation alter aquatic ecosystems, ecological integrity, and water quality (Hyangya et al., 2022). It is recognized that wetlands of freshwater ecosystems not only contain the value of biodiversity and serve as habitats for flora and fauna species but also can deliver many environmental and economic services (Xu et al., 2019). It is also an exceptional, productive ecosystem which is the ecological linkage between terrestrial and aquatic biodiversity (Erwin, 2009).

Wetlands play important hydrological functions including groundwater recharge and purification and flood protection and it is also rich in biodiversity by supporting the food web. With their value in storing carbon within their livings and preserving plants' biomass (peat) instead of releasing it to the atmosphere as carbon dioxide, wetlands help to moderate global climatic conditions. On the other hand, management, clearing, and draining affects wetland ecosystem health including releasing carbon dioxide into the atmosphere (Erwin, 2009).

Due to the effects of human activities and natural factors, the area of wetlands in the world has been decreasing, and their quality has been deteriorating. Impacts on wetlands can be divided into wetland transformation and wetland destruction where 42% have been affected by agriculture and aquaculture activities (Xu et al., 2019). Conversion of wetlands for activities related to agriculture has mostly involved drainage for irrigation and soil improvement; these measures have often destroyed wetlands' ecological character and the ecosystem services that go with them. The alteration of water flow regimes is claimed to be the most serious and continuing threat to the ecological sustainability of aquatic environments that strongly influence organisms directly via their habitat changes (Verhoeven & Setter, 2010).

Irrigation or activities associated with it like dams cause impacts on wetland ecological resources ranging from localized and indirect, to long-distance and severe. The relationship between irrigation and its effects on wetland ecosystems has often been described as a tension between the human need for food versus nature. The reality is much more complex, as both human systems and natural ecosystems may be both adaptive. Benthic organisms are sensitive to disturbance in wetland ecosystems, and the ecological impacts of irrigation or water alterations for benthic organisms can occur over a short distance from the dam or irrigation site. or many miles downstream (Galbraith et al., 2005)

Economic growth in Rwanda relies critically on agricultural growth, yet Rwanda's agricultural sector faces critical limitations such as arable land fragmentation, dependence on irregular rainfall, and challenging topography. As the country's agriculture is mostly rain-fed, production is exposed to climatic variation and unreliable rainfall. As such, irrigation presents a mechanism to intensify Rwanda's agricultural production (Kondylis et al., 2018) to mitigate problems associated with the long dry season and food security. The Eastern Province, the driest and warmest part of the country with the lowest topography, is the region highly affected by drought due to the low amount of rainfall. especially in the Kayonza district (Hakizimana, 2018).

In this district, eight of twelve sectors have been identified as the most drought vulnerable with an estimated 26% of its land surface experiencing severe drought (Hakizimana, 2018). These areas are relatively hot with limited rainfall and a long dry season compared to the rest of the country. Fortunately, Kayonza district has potential for irrigation because of its wetlands. Therefore, the Ministry of Agriculture and Animal Resources (MINAGRI) through the Rwanda Agriculture and Animal Resources Development Board (RAB) is implementing a project entitled Kayonza Irrigation and Integrated Watershed Management Project (KIIWP) with the main goal of contributing to poverty reduction in the drought-prone Eastern Province of Rwanda, Kayonza district by promoting irrigation. MINAGRI has collaborated with the Center of Excellence in Biodiversity and Natural Resource Management (CoEB) at the University of Rwanda to monitor the impacts of irrigation on wetland ecosystems.

The studies carried out by the CoEB for this project included monitoring indicators of wetland ecosystem health to ensure sustainable protection of wetland ecosystem function and climate change mitigation (Verhoeven & Setter, 2010) through investigating responses of benthic communities to irrigation. Responses of benthic organisms to the implementation of irrigation systems can indicate potential stress on wetlands (Galbraith et al., 2005). In this study, we have focused on the ecological effect of irrigation on wetland deterioration using benthic macroinvertebrates as indicators based on their recent assemblage. These include downstream, upstream, and within dam effects on benthic macroinvertebrate communities. Evaluating the ecological effect of irrigation on wetland health using benthic macroinvertebrates could become an important index to promote effective intensified agriculture required to achieve the goals of food security and poverty reduction as targeted in the agricultural policy of May 2000 and wetland health sustainably (N. L. Nabahungu, 2020).

1.2. Problem statement

Freshwater ecosystems are multi-functional ecosystems, and whole communities are dependent upon their productivity and hydrological benefits. In Rwanda the response of farmers to the pressure on land and long dry season associated with the decline in productivity has been to expand their agricultural activities into the fragile wetlands (L. N. Nabahungu, 2012) which can lead to the loss of productivity of arable lands, food insecurity, climate change, and environmental degradation. Their importance for both the human population and the environment would be affected. These reveal an urgent need to improve food security and ecological sustainability (Bidogeza, 2011). Mwiri, Gahini, Murundi, Ndego, Kabare, Murama, Kabarondo, and Rwinkwavu sectors have been identified as the most droughts vulnerable among 12 sectors of Kayonza district in the Eastern Province of Rwanda experiencing a severe drought with limited rainfall and long dry season compared to the rest of the country (Hakizimana, 2018).

Consequently, agriculture in Kayonza district is largely climate dependent, and experiencing issues of climate change, and environmental degradation, and has large implications for agricultural production, food security, nutrition, and in turn, the social and economic welfare of the population. Fortunately, Kayonza district has potential for irrigation because of the presence of wetlands. Therefore, the Ministry of Agriculture and Animal Resources (MINAGRI) through the Rwanda Agriculture and Animal Resources Development Board (RAB) in partnership with the University of Rwanda was implementing a project entitled Kayonza Irrigation and Integrated Watershed Management Project (KIIWP) with the main goal of contributing to poverty reduction in the drought-prone Eastern Province of Rwanda, Kayonza district by promoting irrigation (Aremu et al., 2021).

Supporting rain-fed agriculture with irrigation is needed in the regions like Kayonza but irrigation may have effects that could alter the value and importance of wetlands as freshwater ecosystems. Drainage for irrigation and damming system which serves as flood control during the rainy season and as drought adaption during the dry season by storing water for irrigation can affect wetland ecosystem health and facilitate other threats (agrochemicals circulation, erosion, soil cracks, and floods effect) when the environmental impacts are not well assessed before their implementation and not monitored during and after the whole irrigation activities. However local communities’ adaptation to climate change requires measures that simultaneously respond to human needs, and protect or restore biodiversity and ecosystem services. and remove atmospheric greenhouse gases (Mukankubana, 2020).

The need for ecological wetlands protection and promoting effective irrigation systems for both climate change adaptation and wetland value sustainability of wetland led to this study aimed to evaluate the ecological effects of irrigation on wetland health using benthic macroinvertebrates in the drought-prone area of Kayonza district, Rwanda.

Benthic macroinvertebrates are relatively sedentary with a large number of taxa showing a known degree of tolerance to disturbance and reflecting significantly to the different sources of pollution and deterioration of wetlands. This makes them good indicators of wetland ecosystem health (Griba et al., 2017). The response of benthic macroinvertebrates to changes in their habitats allows them to be used as indices to monitor freshwater ecosystem alteration for supporting decision-making (Tampo et al., 2021).

Additionally, the use of environmental variables alone does not provide as effective information as using aquatic organisms in ecological studies because the aquatic community demonstrates the health of the studied area by integrating the structure and function characteristics (Doretto et al., 2021). A sedentary lifestyle and response to environmental alteration make benthic macroinvertebrates good indicators that enable rapid assessment of the impacts of irrigation on wetland ecosystems (Kim et al., 2019). The major challenge in public wetland reclamation is to follow an integrated approach to achieve economically viable and environmentally sustainable use but wetlands must be managed skillfully to achieve economic benefit while preserving the habitat and hydrological functions that wetlands provide, and that are of such great importance to long-term environmental stability (N. L. Nabahungu, 2020).

Most research on the influence of environmental factors on macroinvertebrate communities focus on large rivers, while relatively few examine small watercourses in agricultural areas, which are likely very affected due to their size and surrounding pressure from intensive agricultural production (Brysiewicz et al., 2022). It is important to provide a means of ensuring future development that is sustainable and able to protect biological richness and ecosystem functions (Munasinghe et al., 2021).

Therefore, it is important to conduct this study to identify the effects of irrigation on freshwater ecosystems using benthic macroinvertebrates, which contribute to maintaining wetland ecosystem health, providing basic information necessary for agriculture, and improving awareness during the implementation of irrigation activities. This study will contribute to climate change adaptation, wetlands protection, and improvement of irrigation to support agriculture in the way of sustainable development goals achievement and one health approach implementation for both humans and nature.

1.3. Goal and objectives

The main goal of this study was to evaluate the ecological effect of irrigation on wetland health using benthic macroinvertebrates as indicators to promote effective irrigation for socio-ecological problem mitigation in drought-prone areas of Kayonza district, Eastern Province of Rwanda.

The following are the specific objectives:

- Identify the benthic macroinvertebrate community and indicator species of wetland health in the study areas.
- Identify potential interaction between benthic macroinvertebrates and wetland use practices in the study areas.
- Develop a baseline for monitoring wetland ecosystem health basing on indicator species of benthic macroinvertebrates sampled in the study areas.

1.4. Research questions

This research is aimed at responding to the following questions:

- Does benthic macroinvertebrates assemblage vary with stream location (upstream, within the dam, downstream)?
- What is the relationship between benthic macroinvertebrates diversity (taxon) and substrate type?
- Is there a relationship between benthic macroinvertebrate assemblage and wetland use practices in the study areas?

1.5. Hypothesis

- There is no difference between benthic macroinvertebrate diversity and abundance upstream, within the dam, and downstream.
- There is no relationship between the occurrence of benthic macroinvertebrates diversity and substrate type.
- There is no relationship between benthic macroinvertebrates assemblage and land use practices.

1.6. Significance of the study

It is important to evaluate the ecological effect of irrigation systems on wetland health using benthic macroinvertebrate indicators in the drought-prone area of Kayonza district to address a critical intersection of intensified agriculture, wetland protection and climate change adaptation in the wetland ecosystem. This study provides essential insights for sustainable biodiversity, scientific evidence for policymakers to adjust regulations on irrigation, skills on ecological effect of irrigation, raising awareness on how to mitigate the negative impact on wetlands, and promoting sustainable irrigation practices as a climate change adaptation strategy for both wetland protection and food security issues.

CHAPTER II. LITERATURE REVIEW

2.1. Wetland ecosystem health status and challenges

A healthy ecosystem is essential to provide the services that humans and the natural environment require with great social and economic value. Sustainability and resilience are considered to be critical factors for ecosystem health and its assessment (Lu et al., 2017). The alteration of water flow regimes for damming and irrigation is claimed to be the most serious and continuing threat to the ecological sustainability of wetlands and strongly influences organisms directly via changes to habitat (Munasinghe et al., 2021).

Dams are well-known in the world because of their various benefits and services such as flood reduction, irrigation, recreation, and hydropower; on the other hand, they disturb aquatic ecological connectivity by fragmenting water systems and modifying the stream water flow. The transport of sediment changes the physical and biological structure of water both upstream and downstream (Wang et al., 2013b).

As the extraction of water for irrigation is threatening the ecology of the wetland and its ability to maintain a viable stock of aquatic organisms, it is clear that the amount of water extracted for irrigation should be reduced while the demand for water for irrigation has increased day to day mainly in the dry season, but the water supply is limited (Street, 2008). However, irrigation is a crucial mechanism in regions with rain-fed agriculture that definitely can cause opposing effects on wetland ecosystem health in the absence of effective implementation and monitoring (Galbraith et al., 2005).

With 11% of the total land, the Rwandan government considers wetlands as an important resource for agriculture intensification, which is required to achieve the sustainable development goals number one and two (food security and poverty reduction) (N. L. Nabahungu, 2020). Due to land use conversions, overuse of water, competition for resources, and climatic factors (Basin, 2019). Rwanda's wetlands are the fastest lost and degraded compared to any other ecosystems in the country (N. L. Nabahungu, 2020). Another climate risk is that heavy rainfall during high precipitation leads to rapid runoff and flooding mainly due to the removal of vegetation, which reduces groundwater recharge because too much rain at one time exceeds soil absorption capacity (Change & Profile, 2019). To assess ecosystem health status, it is necessary to quantify ecosystem situations using a variety of indicators (Lu et al., 2017).

2.2. Bioindicators of ecosystems health

Species indicators of ecosystem health are organisms that should represent key information on the structure and function of the ecosystem and be specific for the goal of the assessment, therefore they are classified by the system of ''stress, exposure and habitat, and response'' (Lu et al., 2017) as they respond to any condition(s) of the environment where they live (Siddig et al., 2016). Bioindicators refer to all sources of biotic and abiotic reactions to ecological changes as well as to indicate negative or positive impact due to the presence of pollutants which can affect the biodiversity of the environment (Parmar et al., 2016). Stressor indicators quantify a natural process, an environmental hazard, or a management action that affects changes in exposure and habitat.

Exposure and habitat indicators identify the degree to which a system or its components might experience and respond to the stressor while response indicators are measured to provide evidence of the biological condition of a resource at the level of organism, population, community, or ecosystem (Lu et al., 2017). The value of using bioindicators in ecosystem monitoring rests on the fact that it can help identify priority sites for conservation, and it uses organisms that are relatively easy to identify. This is essential for citizen engagement and drawing a long-term link between policymaking, on-the-ground practices and impacts on freshwater ecosystems (Uyizeye et al., 2021).

2.3. Benthic macroinvertebrates as indicators of wetland ecosystems health

Among the biological communities, the most known bioindicators of wetlands ecosystem health are benthic macroinvertebrates with clear responses to wetland conditions reflected by related changes in their community structure (Enawgaw, 2019). They are well-known as indicators of anthropogenic stresses due to their sedentary habitat and maintain various levels of interaction between the community and environment which provides precise and local information on recent events (Brraich & Kaur, 2017).

Benthic macroinvertebrates are small animals without a backbone that live just below the stream bed and are found in sediment (substrate), most of them are enough to be seen with necked eyes with a range of length varies from 0.25 mm to 15 cm (Sripongpun G, 2003). The response of benthic macroinvertebrates to different environmental stressors is a widespread practice for evaluating the quality of water and wetland ecosystem health (Custodio et al., 2018)**.**

The effect of individual environmental parameters (biotic and abiotic) on benthic organisms depends on the tolerance, sensitivity, and adaptability of each particular species to its habitat conditions (Brysiewicz et al., 2022). The presence/absence of tolerant or sensitive benthic macroinvertebrates allows scientists to understand the condition of the stream and surrounding environment as the presence of numerous families of highly tolerant organisms such as aquatic snails, Diptera and worms while the absence of individuals from EPT group which are very sensitive to pollution, usually indicate poor habitat quality (Mandaville, 2002).

The high richness of Ephemeroptera, Plecoptera and Trichoptera (EPT) sensitive bioindicators of stream and wetland health is often considered a good ecological status (Timoner et al., 2021) while the presence of fewer sensitive species within an area gives the impression that the region is vulnerable to climate change and pollution (Timoner et al., 2021). As they are used to detect changes in natural surroundings due to the presence of pollutants which can affect the biodiversity and the environment (Parmar et al., 2016), they show a potential sensitivity to pollution and exposure to climate change (Sandin et al., 2014).

It is important when planning and implementing management and conservation strategies in freshwater ecosystems to identify areas with sensitive taxa and predicted significant changes in climate hence to develop efficient future adaptation strategies to climate change sustainably (Sandin et al., 2014).

2.4. Wetland ecosystems alteration and benthic macroinvertebrates

Based on Sustainable Development Goals purposes (SDGs) 14 & 15 (Life below water and on land) on the transformation of our world by protecting wetlands as the ecological hub between terrestrial and aquatic ecosystems life, the wetland which is important to human health, and well-being, aquatic, and terrestrial life is governed by factors that influence species composition, and diversity, stability, production, and physiological conditions of indigenous populations of both flora and fauna in a water body (Iyiola & Asiedu, 2020).

Due to the increasing water temperature, nutrients and pollutants (agrochemicals) (Fierro et al., 2021a), decreasing in stream surface and water level in the wetland mainly during the dry season (Street, 2008) associated with irrigation in agricultural land use can negatively influence aquatic macroinvertebrates. As consequences are the decrease of sensitive insecta taxa (Ephemeroptera, Plecoptera, Trichoptera), and increased relative abundances of tolerant non-insecta taxa such as snails (Fierro et al., 2021a).

Moreover, macroinvertebrates are omnipresent in aquatic systems and play various roles such as the mixing of sediments, the change of oxygen into the sediment, and the cycling of organic matter, their presence is threatened by changes in their habitat associated with pollution and degradation which varies with time and location (Iyiola & Asiedu, 2020).

2.5. Climate change adaptation and irrigation as a strategy to address drought

An important strategy for addressing drought as a result of climate change in agricultural systems is irrigation and land resource management so that the variability and intensity of water can be controlled and the quality of existing land can be improved (International Labour Organization, 2011). Climate change has increased the intensity, frequency and duration of droughts, turning water management into a more complicated issue (Cotera et al., 2024). Irrigation is being implemented as a strategy to address droughts that affect agricultural productivity, which contributes to agricultural intensification; it is believed that irrigation does not impair freshwater resources and aquatic ecosystems (Rosa et al., 2022). However, with increasing episodes of drought affecting agricultural productivity, it is important to understand the effects of irrigation, a strategy to address drought, on freshwater ecosystems. Promoting science-based decision-making regarding climate change adaptation reduces the risk of implementing measures which could lead to maladaptation (Cotera et al., 2024) by linking poverty reduction and food supplies with sound climate change adaptation strategies (International Labour Organization, 2011).

CHAPTER III. METHODS

3.1. Study area

This study was conducted in the Eastern province of Rwanda, in Kayonza district located in the Akagera lower catchment within the Nile basin. Kayonza district covers an estimated total surface area of 1.954 km2 and is bordered by the district of Rwamagana to the west, Gatsibo to the north, Ngoma in the south-west and Kirehe to the south-east and the United Republic of Tanzania to the east.

The study sites are located within the targeted KIIW project area. This project started in 2019 and comprises eight drought-prone sectors out of 12 sectors of Kayonza district, in the Eastern Province of Rwanda. Those sectors are Mwiri, Gahini, Murundi, Ndego, Kabare, Murama, Kabarondo, and Rwinkwavu, the two largest sectors of them, Mwiri and Murundi were selected for this study because of their interconnected wetlands namely Kageyo, Gatindo, and Mucucu (Figure 1). The Kageyo dam which serves agriculture irrigation was constructed in 2018 while the Gatindo dam which serves both livestock and agriculture irrigation was constructed in 2002 and upgraded in 2021 by KIIWP, both are located in the Mwiri sector while Mucucu also known as Cyamusenyeri dam mainly serves livestock activities is located in the Murundi sector was constructed in 2002, rehabilitated in 2016, and upgraded in 2022 by KIIWP.

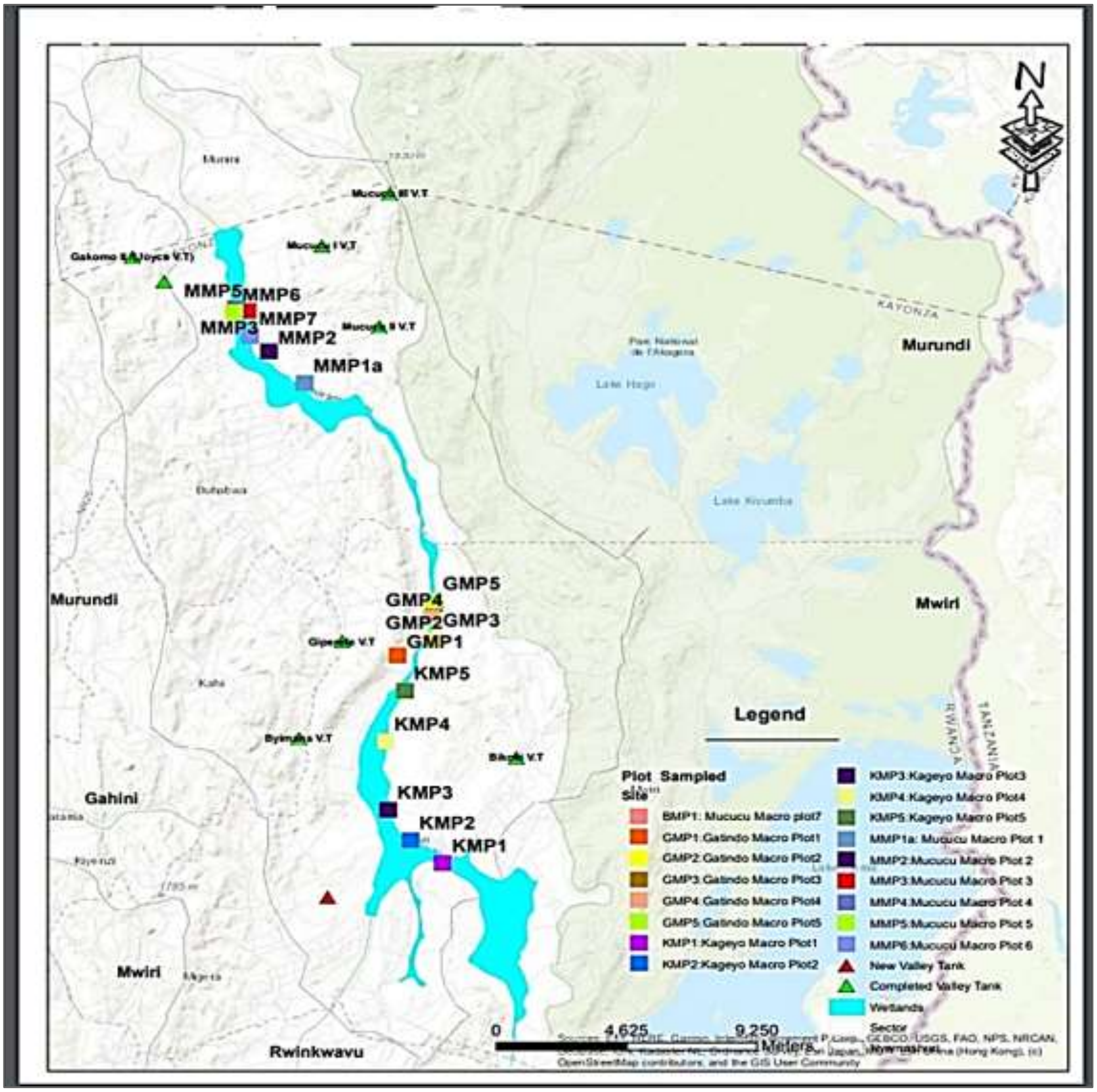

Figure 1: Wetlands of Kageyo -Gatindo-Mucucu sampling sites in Kayonza district

3.2. Macroinvertebrate sampling

Benthic macroinvertebrates were collected in the season of low precipitation (October 2021) and the season of high precipitation (May 2022) with an interval of seven months from Kageyo, Gatindo (in Mwiri sector), and Mucucu (in Murundi sector) wetlands depending on KWIIP target for irrigation. Sampling was done in 14 plots according to Kageyo, Gatindo, and Mucucu targeted dams' locations in both periods of precipitation, with four plots in the Kageyo site, five plots in Gatindo, and five plots in the Mucucu sites. Plots were upstream, direct within dams, and downstream of dams with approximately one square meter for each plot (Simeonova et al., 2003) but the upstream Kageyo site was out of my study areas delimitation so that it was not sampled (Table 1).

The study areas Kageyo-Gatindo-Mucucu were selected because they are interconnected wetlands from KWIIP target irrigation activities areas with crucial sources of water but located in drought-vulnerable areas due to climate change as shown in research done by Hakizimana in 2018. The samples were collected from five plots upstream, four plots direct within dams and five plots downstream with two or three times for samples trapping in one plot to maximize samples, the same plots were sampled for both periods (low and high precipitation). The plots were selected according to the accessibility of the area, location of the stream, and disturbance such as land use activities like agriculture, farming, and activities related to irrigation. Such sampling is known as spot sampling approach.

Benthic macroinvertebrates were sampled using the kick net method with a D-frame dips net called a kick net. This is the method used to collect benthic macroinvertebrates in water streams. A Dip net is a device with 500-micrometer net mesh and it is either cone or bag-shaped for the capture of organisms where the widest part of the "D" attaches to a long pole easy to transport. We used this method to trap macroinvertebrates in water by holding the net while slowly approaching the sample place, and then we put the net slowly into the water to minimize some disturbance. We set the net vertically with the frame at right angles to the water flow, downstream from feet, and we disturbed the stream bed vigorously by kicking or rotating the wheel of the feet to dislodge the substratum and the fauna within the plot (Rosenberg et al., 1998). I deposited the samples with substrate aside in white plastic basins for easy inspection by hand-picking with forceps and recording the type of substrate observed such as mud, sand, plant debris, soil, etc. Labels on each sample consisted of GPS coordinates from where samples collected, period in which sampling was done, site, land use practice in the site, stream location and substrate type later to be able to achieve our objectives and to assess the hypothesis. We conserved the collected samples in highly concentrated ethanol and labeled them for later identification.

Water quality parameters (pH, temperature, dissolved oxygen, turbidity, and total dissolved solids) were recorded directly using multimeter device, land use practices (agriculture and farming activities), land degradation (soil cracks. effect of erosion and floods), and substrate type were also recorded. Also, a handheld GPS receiver was used to take the coordinates of sampled plots for mapping. Some photos were taken using a camera for enriching information. Spot sampling approach was used to collect data in both periods of precipitation (low and high precipitation) across all plots of study sites and labeled separately.

Table 1: Sampled plots by location in each site for both low and high precipitation periods

Sites	**Number of plots by sample location**			**Number of plots by study site**
	Upstream	Within dam	Downstream	
Kageyo	0	1	3	4
Gatindo	3	1	1	5
Mucucu	2	2	1	5
Total plots	**5**	**4**	**5**	**14**

3.2.1. Conservation of samples in the laboratory

After each sampling period, all samples were conserved separately according to their sampling site, stream, and plot location in the biology laboratory of the University of Rwanda (Huye campus). Water parameters and substrate type were recorded on the field. BMI were conserved in small battles within ethanol concentrated at 96.4% to prevent them from being damaged.

3.2.2. Benthic macroinvertebrates identification

The identification at the family level was performed using identification keys in the biology laboratory of the University of Rwanda (Huye campus) using a stereo microscope and magnifying lenses for physical appearances such as differences in the head, body shape, and placement of feathery external gills, coloration, and the number of tails. The specimens were separated depending on their family levels and then labeled (Davies & Tsomides, 2002)(Davies & Tsomides, 2002)**.**

3.2.3. Data analysis

After identifying collected specimens, the data of diverse benthic macroinvertebrates families from all sites of studied areas were entered into a spreadsheet hence to be processed and analyzed using Analysis of Variances (ANOVA) which is a statistical method used to compare variances across the average of different groups hence to determine differences between results from more than two unrelated samples of BMI from different streams and sites; this test was used to test for differences in BMI samples between the stream sample sites and to test the hypothesis about relationship during categorical data analysis and results interpretation.

Shannon diversity index was calculated to compare diversity across the sites using the formula $H' = -\sum(P_i \times \ln P_i) = -\Sigma [(n_i/N) \times (\ln n_i/N)]$ (Turkmen, 2010), where ni: number of individuals belonging to each species, N: Total number of individuals and ln: Natural logarithm, is used to measure species diversity of benthic macroinvertebrate and abundance. Higher value of H' means greater diversity while lower value indicates less diversity that helped us to make interpretation of results for understanding and comparing diversity of BMI sampled.

CHAPTER IV. RESULTS

4.1. Benthic macroinvertebrate community structure

A total of 1191 individuals from 22 families of benthic macroinvertebrates (BMI) were recorded in low and high precipitation across all 14 plots location (upstream, within dam, and downstream of dams) with Shannon Diversity Index (H) =3.745). In low precipitation, 967 individuals from 15 families were found (H=2.772) while in high precipitation 224 individuals from 19 families (H=0.973) and some BMI taxa were found in both low and high precipitation across all study sites.

Table 2: Benthic macroinvertebrates taxa and abundance sampled by the period of precipitation

BMI Families	Abundance in high precipitation	Abundance in low precipitation	Abundance in total
1. Thiaridae	28	369	397
2. Belostomatidae	24	125	149
3. Chironomidae	55	68	123
4. Planorbidae	24	99	123
5. Hydrophilidae	8	104	112
6. Physidae	12	60	72
7. Lymnaeidae	14	44	58
8. Ampullaridae	14	26	40
9. Bulinidae	17	11	28
10. Dytiscidae	4	23	27
11. Unidentified mayflies	0	15	15
12. Hirudinidae	8	0	8
13. Unionidae	1	7	8
14. Coenagrionidae	1	6	7
15. Libellulidae	7	0	7
16. Nepidae	0	7	7
17. Simuriidae	0	3	3
18. Limnichidae	2	0	2
19. Tateidae	2	0	2
20. Aechnidae	1	0	1
21. Conoesucidae	1	0	1
22. Tipulidae	1	0	1
Grand Total	**224**	**967**	**1191**

Sensitive species of benthic macroinvertebrates recorded in this study were from Phylum Arthropoda (Class Insecta) such as Ephemeroptera (mayflies) and Trichoptera (Conoesucidae) while tolerant species were mainly non-Insecta from Phylum Mollusca such as Thiaridae and Annelida (Hirudinidae), although Diptera (Chironomidae) was also recorded among known tolerant Insecta in this study (Table 3). During this study, 59% of all sampled BMI taxa were Insecta while 41% were non-Insecta with 36% from Mollusca and 5% from Annelida (Figure 2).

Although Insecta taxa were more common than non-Insecta taxa, individuals from non-Insecta were more abundant than those of Insecta classes.

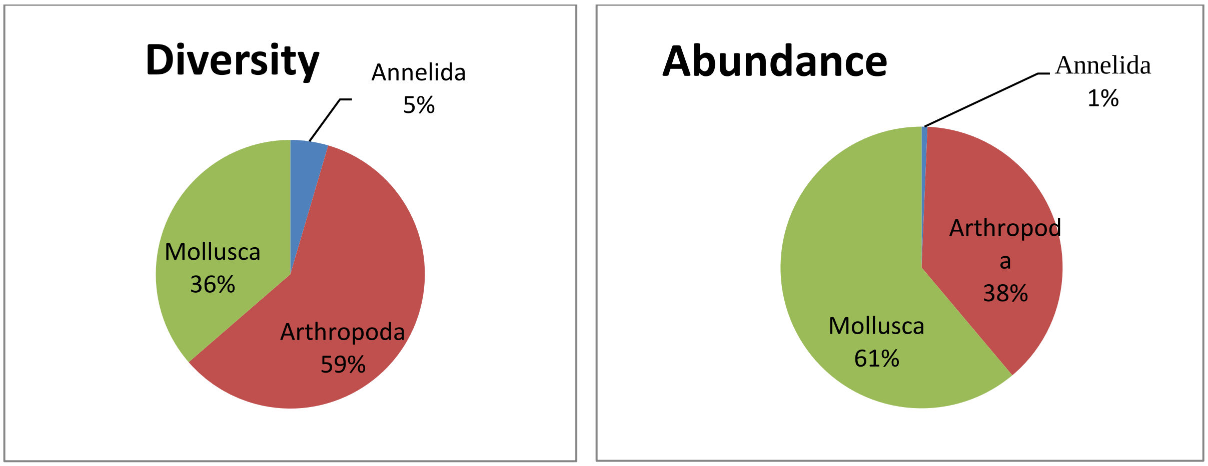

Figure 2**:** The proportion of Insecta and non-Insecta (Mollusca and Annelida) in BMI samples (diversity and abundance) according to their Phyla

4.2. BMI community structure and stream locations (upstream, within dam and downstream)

We have sampled upstream (5 plots), within dam (4 plots), and downstream (5 plots) locations across all study sites (Table 1), and the significant impact of stream location on the benthic macroinvertebrates was observed (F statistic=0.716827, df=8, P value =0.0215). In general, BMI decreased respectively from downstream and upstream to within dam location (Figures 3 and 4).

Among stream locations, BMI varied in community structure (diversity and abundance) and in the presence of sensitive and tolerant taxa, where some BMI were present or absent depending on their sensitivity to the stream conditions. Tolerant BMI from Mollusca were observed abundantly downstreams (87.4%) more often than upstream and within dam while Insecta were abundant (81.3%) upstream with 23.1% of tolerant insecta (Diptera) and 5.5% of sensitive BMI (Ephemeroptera) recorded abundantly upstream than downstream and within dam.

During this sampling study, no Plecoptera individuals were recorded in all streams, and no Ephemeroptera, Trichoptera (T), or Plecoptera (P) individuals were recorded within dams during the whole sampling study.

Table 3: Percentages of non-insecta and insecta (sensitive/tolerant) among stream locations

<table>
<tr><th>BMI</th><th colspan="5">Upstream (273 BMI individuals)</th><th colspan="5">Within dam (206 BMI individuals)</th><th colspan="5">Downstream (712 BMI individuals)</th></tr>
<tr><td rowspan="3">non-Insecta</td><td colspan="5">18.7%</td><td colspan="5">29.6%</td><td colspan="5">87.4%</td></tr>
<tr><td colspan="3">Mollusca</td><td colspan="2">Non Mollusca</td><td colspan="2">Mollusca</td><td colspan="3">Non Mollusca</td><td>Mollusca</td><td colspan="4">Non Mollusca</td></tr>
<tr><td colspan="3">99.6%</td><td colspan="2">O.4%</td><td colspan="2">97.6%</td><td colspan="3">2.4%</td><td>99.7%</td><td colspan="4">0.3%</td></tr>
<tr><td rowspan="3">Insecta</td><td colspan="5">81.3%</td><td colspan="5">70.4%</td><td colspan="5">12.6%</td></tr>
<tr><td>E</td><td>P</td><td>T</td><td>D</td><td>Other taxa</td><td>E</td><td>P</td><td>T</td><td>D</td><td>Other taxa</td><td>E</td><td>P</td><td>T</td><td>D</td><td>Other taxa</td></tr>
<tr><td>5.5%</td><td>-</td><td>-</td><td>23.1%</td><td>71.4%</td><td>-</td><td>-</td><td>-</td><td>8.7%</td><td>91.3%</td><td>-</td><td>-</td><td>0.1%</td><td>6.4%</td><td>93.5%</td></tr>
</table>

As shown in the Table 3, non-Insecta individuals were more common in downstream locations (87.4%) while Insecta individuals were more abundant in upstream locations (81.3%). A significant difference was also observed between non-Insecta and Insecta of the same stream where:

- Upstream: non-Insecta were 18.7% with 99.6% of these from Mollusca and 0.4% Hirudinidae while Insecta were 81.3% of the sample, with 5.5% individuals of Ephemeroptera (mayflies) and 23.1% Diptera [Chironomidae (22.7%) and Simuliidae (0.4%)].
- Within dam: non-Insecta comprised 29.6% of the sample with 97.6% of these in Mollusca and 2.4% Hirudinidae; Insecta were 70. 4% with 8.7% of Diptera (Chironomidae).
- Downstream: non-Insecta comprised 87.4% of the sample with 99.7% of these being Mollusca and 0.3% Hirudinidae while Insecta comprised 12.6% of the sample with 0.1 % of Tricoptera and 6.4% of Diptera (6% Chironomidae, o.3% Simuliidae and 0.1% Tipuliidae).

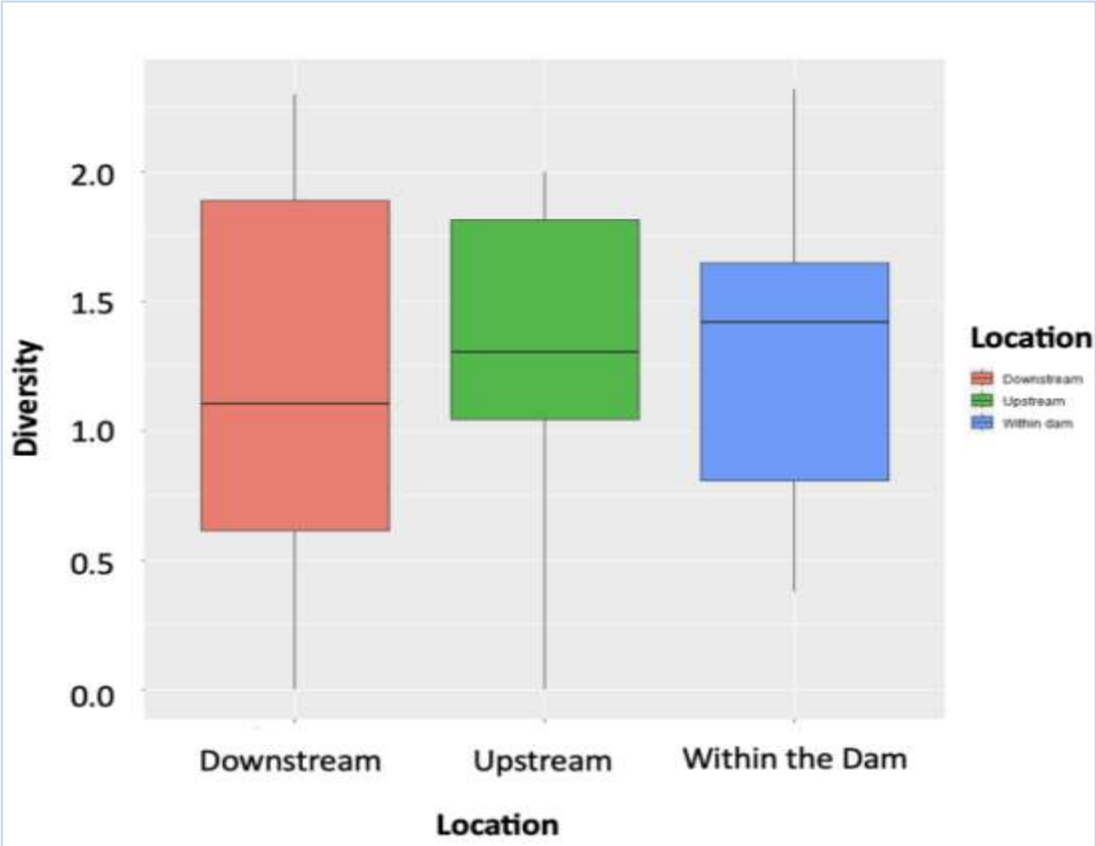

Figure 3: General presentation of BMI diversity upstream, within dam and downstream of the dams for all study sites

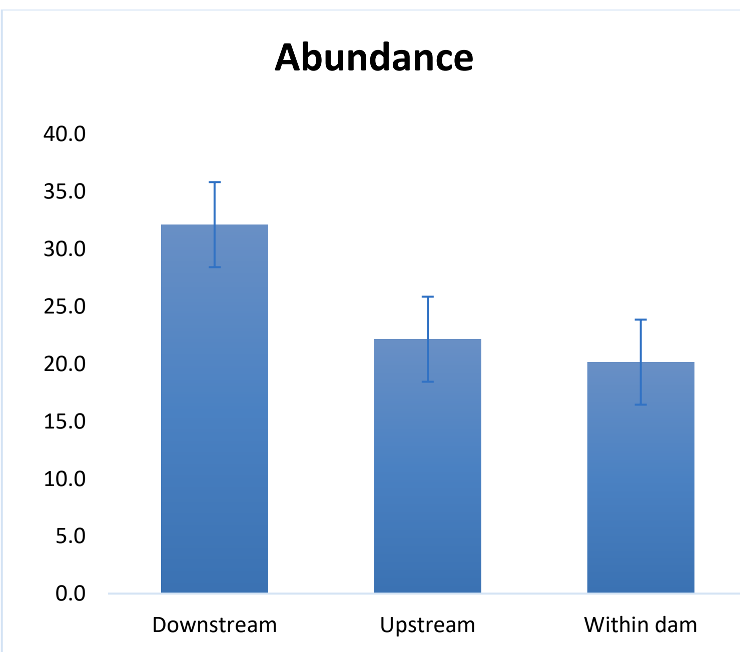

Figure 4: BMI abundance upstream, within dam, and downstream of the dams for all study sites

4.3. Influences of seasons, land use practices and water quality on BMI in stream

I observed that physical (temperature, turbidity), chemical (PH, TDS) and biological (DO) parameters varied with adjacent land use practices, irrigation system or/and rainfall. All these conditions have an impact on the life of organisms in benthic habitats and influence their community structure.

Downstream of Kageyo were the areas of intensive agriculture activities irrigated by water from Kageyo dam; I found dissolved oxygen (DO) at 4.8mg/l in low precipitation and 2.8mg/l in high precipitation, 28.3ºC in low precipitation and 26.6ºC in high precipitation. This area seemed to be richest in BMI (diversity and abundance) with a great abundance (59.8%) of total sampled individuals composed of a big number of non-Insecta (87.4%) due to the significant Thiaridae individuals (55.8 %) recorded only at downstream Kageyo site as shown in Table 3 and Appendix 1, especially in the mud substrate of water drained from the rice plantation at Kageyo plot3 (KMP3) during the period of low precipitation.

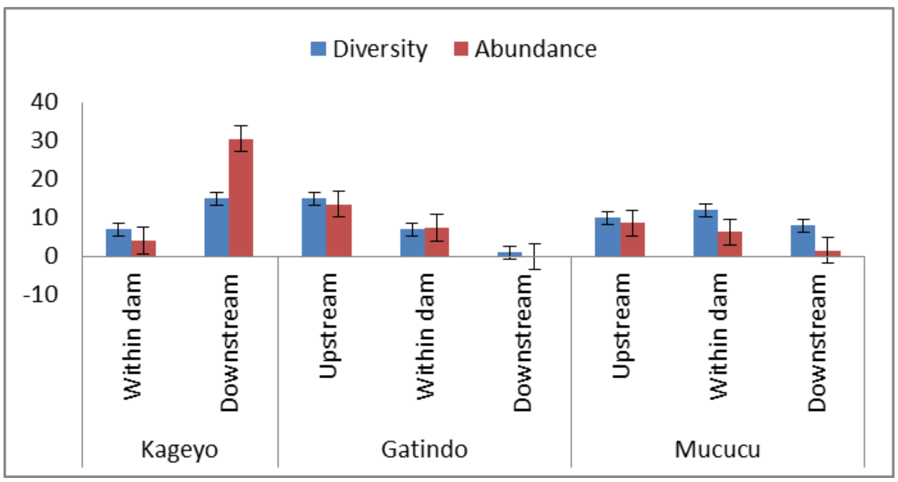

Figure 5: BMI community structure (diversity and abundance) upstream, within dam and downstream in each study site.

However, BMI from all downstream locations was greater than other stream locations but the poorest streams of the study sites also were observed downstream locations (0.1% individuals from Gatindo and 2.2% individuals from Mucucu) as shown in Figure 5. This significant decrease was induced by the absence of BMI individuals in the sample from Gatindo downstream during high precipitation likely due to the effect of a cement-made canal draining water from Gatindo dam and only Belostomatidae taxon with one individual was recorded during low precipitation (Appendix 1). The absence of BMI individuals was also observed at Mucucu downstream as a result of high turbidity (17.1NTU), temperature (27.5ºC), and phosphate (0.34mg/l) influencing high eutrophication and abundance of phytoplankton observed, which reduced dissolved oxygen (o. 4 mg/l) and inhibited the presence of benthic organisms.During sampling periods, Kageyo site was dominated by agriculture activities while at Gatindo site agriculture and farming activities were moderated. The Mucucu area was dominated by livestock activities and fewer agriculture activities.

A significant difference among BMI across Kageyo, Gatindo, and Mucucu study sites was observed (F statistic=0.432046, df=8, P value=0.048944) related to the land use practices types (agriculture and livestock activities) imposing different effects (agrochemical substances, organic components from crops and cattle excretion, water quality changed, water scarcity and land degradation) influencing other disturbances (erosion, floods, soil cracks) and as result BMI assemblage changed with land use changes. I have observed that water parameters changed with land use types, which also correlated with the proportion and composition of BMI in streams of each study site.

Table 4: Impact of seasons on stream water quality parameters and land use practices by study site

Stream locations/Sites		Water quality parameters (Means)										Land use practices
		Low precipitation					**High precipitation**					
Kageyo	Stream	DO	T°	PH	TDS	Turbidity	DO	T°	PH	TDS	Turbidity	Irrigation Damming Intensive agriculture activities Land consolidation Near road and settlements No buffer zone
	Within dam	0.4	27.2	7.9	283	18.4	8.6	26.9	7.85	154.4	30.7	
	Down stream	4.8	28.3	7.5	242.6	57.6	2.8	26.6	6.8	172.6	28.4	
Gatindo	Up stream	2.4	29.4	6.4	332	31.4	1.6	24.8	6.8	153.1	13.9	Irrigation Damming Moderate agriculture Farming No buffer zone
	Within dam	3.7	29.7	6.5	417	37.2	5	25.2	6.9	152.7	18.2	
	Downstream	2.9	28.8	6.4	389	73.2	0.87	22.4	6.77	230	15.5	
Mucucu	Upstream	0.2	25.7	6.3	304.5	20	2.6	24	6.9	181.7	24.2	Irrigation Damming Fewer agriculture activities Intensive farming activities, No buffer zone
	Within dam	6.1	28.1	7.1	265.5	10.7	1.9	24.7	6.7	235	36.6	
	Downstream	0.4	27.5	6.45	287	17.1	0.9	22.4	6.8	230	15.5	

17. 3% of all BMI individuals recorded in this research were sampled within dam (depending on dam water conditions) in the following ways:

- 14. 6% of them, recorded from Kageyo within dam (Figure 5) were dominated by BMI tolerating within dam water conditions (DO, T°, PH, TDS and turbidity) as presented in Table 4, those tolerant BMI were Ampullaridae individuals (40%) and Chironomidae (13.3%).
- 51% of them, recorded from Gatindo within dam (Figure 5) were dominated by Insecta from Belostomatidae (40%), Hydrophilidae (38.1%), and 3.8 % of Diptera (Chironomidae), these BMI individuals tolerate Gatindo within dam water conditions as shown in Table 3.
- 34.5% of them, recorded from Mucucu within dam (Figure 5) comprised 14.1% of Chironomidae (Diptera), 7% of Hirudinidae (Annelida), 16.9% of Ampullaridae (Mollusca) and 11.3% of Bulinidae (Mollusca) while others were in very small percentages. Water parameters of Mucucu dam were presented in table 4.

BMI individuals recorded from upstream locations were 22.9% of all BMI sampled in the following ways:

- 60.8% of them were sampled from Gatindo upstream (Table 3) with 8.4% of Ephemeroptera (mayflies), 7.2% of Diptera (Chironomidae and Simuliidae) and 0. 6 % of Hirudinidae (Annelida) individuals. Water parameters of Gatindo upstream were presented in the table 4.
- 39.2% of them were recorded from Mucucu upstream (Table 3) comprised 47.7% of Diptera (Chironomidae), 0.9% of Ephemeroptera (mayflies); Mucucu upstream water parameters were presented in Table 4.

The great number (60.1%) of all BMI individuals recorded during low precipitation were sampled downstream (Figure 7) with 99.9% from Kageyo downstream with a high abundance of Thiaridae (63.4%) tolerating poor water quality recorded in this area (Appendix 1).

There was significant interaction between streams and seasons during this research across all study sites with consistent differences between seasons (F-statistic=0.026181, df=41, P value=2.69E-12) where higher abundance was recorded in low precipitation (81.2%) than in high precipitation (18.8%) across streams in all study sites. This difference was pronounced in the upstream locations (Figure 6) where 82.1% of all BMI individuals were recorded in low precipitation with 6.7% of Ephemeroptera (mayflies) individuals.

The influence of precipitation on the BMI community triggered the diversity (BMI taxa) to vary proportionally with abundance between periods of precipitation among streams (Figure 7) but differently among abundance of the same streams (Figure 6).

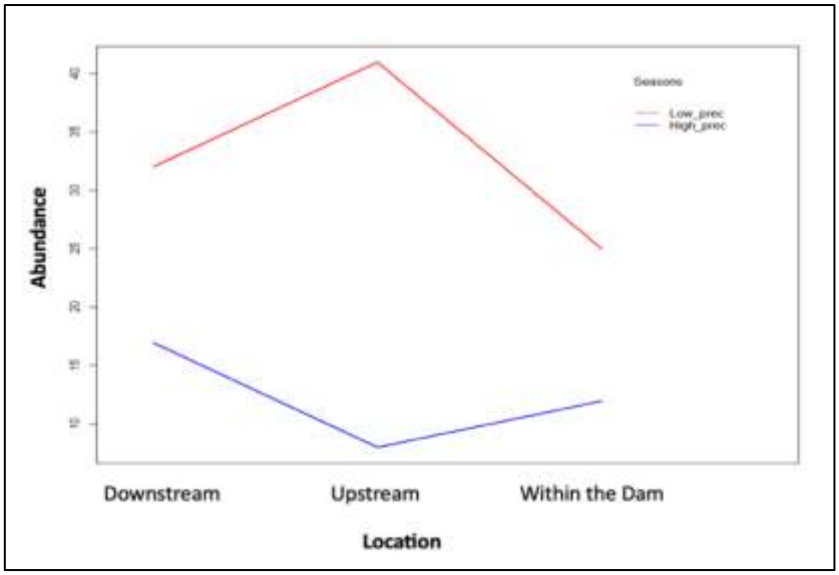

Figure 6: Comparison of benthic macroinvertebrates abundance among streams in low and high precipitation

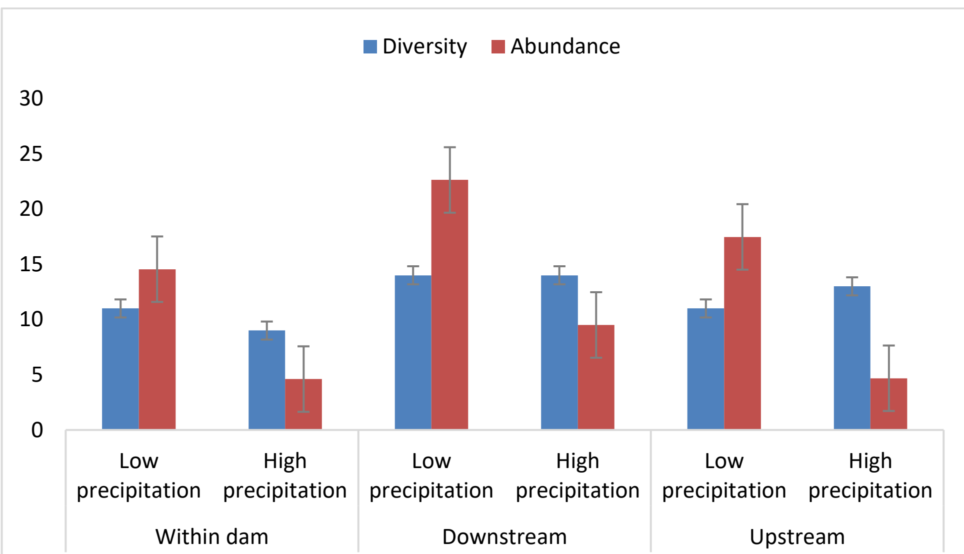

Figure 7: BMI diversity and abundance by the stream in low and high precipitation

4.4. Benthic macroinvertebrates diversity and substrate

During data collection of this study, I sampled BMI individuals from substrate that served as their shelter and I observed that BMI taxa (diversity) were strongly associated with substrate type ($\chi 2$ = = 513.55, df = 391, p-value =2.95 x10^{-4}).

For the greater taxa of Mollusca, non-insecta classes were collected from mud substrate mainly Thiaridae taxa while greater taxa of insecta including sensitive taxa (EPT) were associated with vegetation / grasses substrates so that substrate composed by both mud and vegetation/grasses hosted the greater BMI taxa with

54.5% from the mud only while washed substrate hosted few taxa as many were transported away by irrigation or the flood (Figure 8 and Appendix 1).

In both sampling periods (low and high precipitation) no composition of mud substrate was observed within dam locations but was found abundantly in downstream locations associated with sampled taxa tolerating pollution (Thiaridae), and this indicates the significant ecological difference in BMI downstream and within dams as they are associated with substrate where they live (Figure 8). Upstream locations were dominated by flooded soil substrate composition in low precipitation and grasses (sometimes debris) substrate composition in high precipitation.

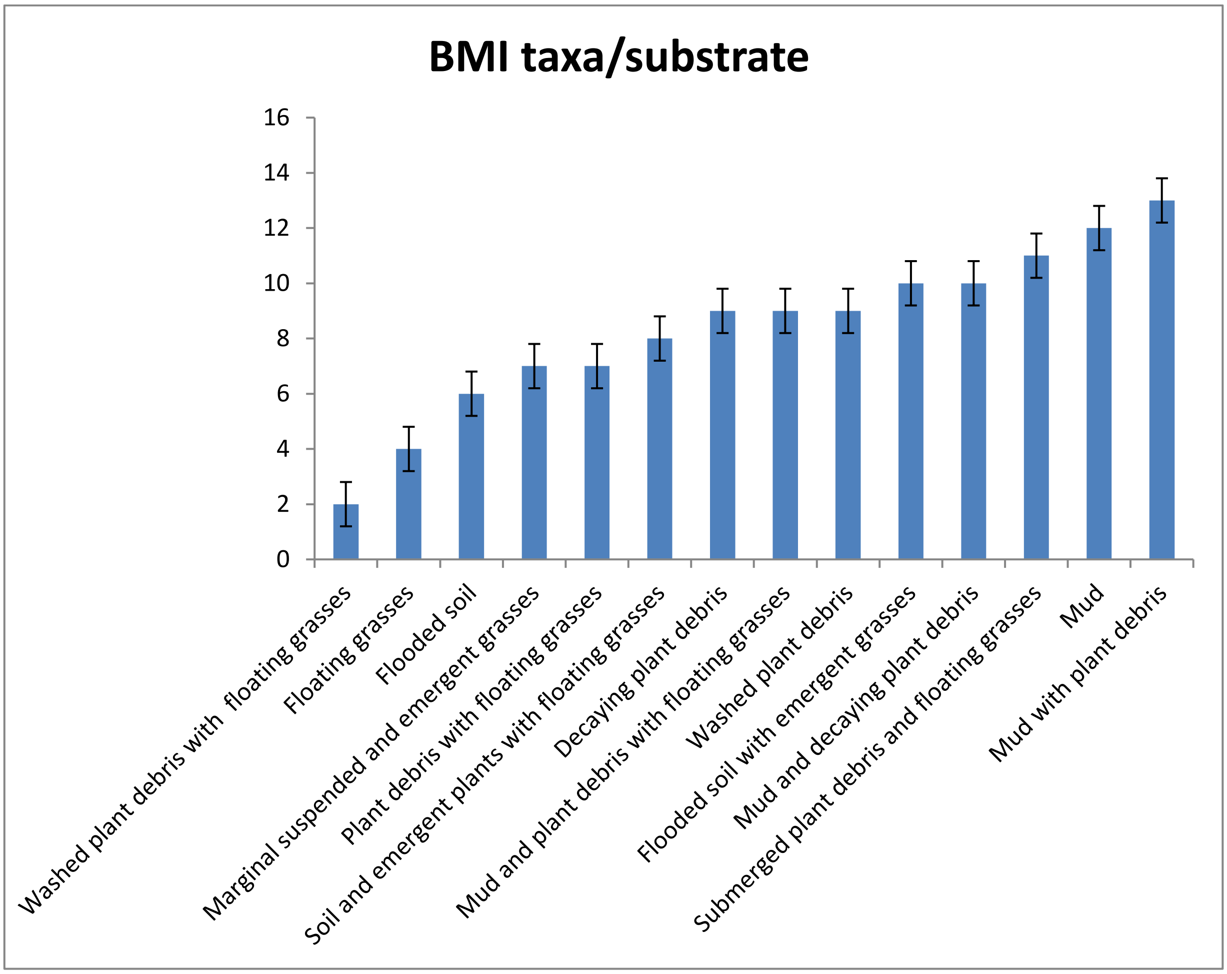

Figure 8**:** Types of substrates and rate of hosted benthic macroinvertebrates taxa (diversity)

CHAPTER V. DISCUSSION

5.1. Benthic macroinvertebrates and stream conditions

We have conducted this research within three interconnected wetlands, Kageyo, Gatindo, and Mucucu. Agriculture and farming activities imposed hydrological modification (dams and irrigation) to be implemented within these wetlands while no buffer zone observed across these study sites. These hydrological alterations, land use practices, and habitat fragmentation cause loss of sediment (substrate) connectivity, resulting in significant changes in stream conditions (substrate and water quality) including benthic macroinvertebrates assemblage (Dusabe et al., 2022), and this was observed especially in downstream sections where water flow influenced run off of pollutants from agricultural land impacted BMI within stream by changing water quality and substrate type. Structure, as well as physical and chemical conditions (water quality) and composition (substrate) of the stream determine the BMI local species assemblage in terms of both abundance and diversity as they are sedentary organisms (Villeneuve et al., 2018). Alteration of stream flow by water management is reported to induce benthos abundance, richness, and diversity (Munasinghe et al., 2021). As a result their community modification due to their habitats change led to the presence of taxa tolerating the current stream conditions and absence of sensitive ones which moved away or died as we have found the parts of their exoskeletons remained during samples collection.

Substrate is the primary physical environmental variable affecting the taxa richness and density of macroinvertebrate community composition (Duan et al., 2008); availability of habitat, a refuge against enemies and other factors (competition for foods, reproductive conditions) directly affects the assemblage of benthic macroinvertebrates that reside in substrates (Fenoglio et al., 2020). In this research, the highest number recorded in mud substrates was attributed to the high number of Gastropoda such as Thiaridae, Planorbidae, Physidae families, and Diptera (Chironomidae) species tolerating the conditions such as temperature of the stream with mud (Khudhair et al., 2019).

Vegetation substrate composition (submerged, floating, debris, and emergent vegetation) supports a greater number of individuals of aquatic invertebrates mainly from insect taxa, as vegetation plays a major role in the assimilation of nitrogen and phosphorus which reduces nutrient concentrations, improving self-purification of wetlands and increases niche space, provides structural support and higher food quality and protection from predators (Khudhair et al., 2019). In this study, I found a high level of benthic macroinvertebrates in substrate composed of mud together with vegetation materials where both non-insecta and insecta were found. It was significantly different in BMI assemblage among substrate types of the same stream than between different streams (Gething et al., 2020) that explains how BMI communities are significantly influenced by substrate types than stream location(Pereira et al., 2017). So that, the previous statements responds to the first and second questions of this research.

As shown by other researchers and as the response to the first research question, this study also demonstrated that the more disturbed or polluted the stream locality (based on water quality and land use practice), the fewer Ephemeroptera, Plecoptera, and Trichoptere (EPT), species typically sensitive to pollution and degradation (Wang et al., 2013a) and the presence of numerous individuals with high tolerance such as snails (Thiaridae, Planorbidae) and Diptera insecta (Chironomidae) (Mandaville, 2002). In this research, numerous individuals of tolerant BMI (Mollusca) without sensitive individuals from E P T group were recorded abundantly in stream locality of Kageyo where intensified agriculture activities were highly applied while sensitive individuals (E P T) were more recorded at Gatindo site of moderate agriculture and farming activities than Mucucu site dominated by livestock activities with significant decrease of Mollusca.

5.2. Benthic macroinvertebrates and wetland use practices

Land use changes and the ways that natural resources are extracted and used pose severe threats to freshwater ecosystems globally (Uyizeye et al., 2021) and influence the stream habitat by inducing substrate composition, water quality, and benthic macroinvertebrates presence/absence due to the types of activities in the areas and their effects**.** The present BMI taxa surviving in such streams have to be tolerant to the present conditions while the sensitive ones were absent in the streams. During this study, I have observed that, chemical components used in agricultural land and components of cattle excretions influence stream ecological balance including water quality and biodiversity by reaching wetlands with the surface flow during rainy seasons (Saglam, 2018) especially through drainages for irrigation stimulated by erosion and floods.

The use of fertilizers, pesticides, mechanization, and residues from crops harvested in the wetland agriculture area was associated with the increase in the proportion of non-insecta individuals that leads to the big number of macroinvertebrates especially downstream (Fierro et al., 2021b). Individuals with high tolerance to pollution and disturbance mainly Gastropoda (Thiaridae, Planorbidae, and Physidae families) tolerating heavy metals from those agrochemical substances and Diptera were abundantly recorded in the Kageyo area dominated by irrigated agricultural activities but no species with high sensitivity to pollution (heavy metals, low dissolved oxygen) such as Trichoptera, Ephemeroptera (Kaaya & Day, 2015) were recorded.

During this research, a significant change due to agriculture activities in the assemblage composition of benthic macroinvertebrates downstream of dams (Wang et al., 2013b) was observed at Kageyo downstream with numerous individuals of Thiaridae taxa. These are aggressive invasive Mollusca, intermediate vectors for Trematoda parasites attributed to muddy substrates from the drainages for irrigation of rice plantation that hold immobile permanent water with temperatures ranging between 18°C and 31°C. Thiaridae individuals tolerate the accumulation of heavy metals (from fertilizers and pesticides) circulated by drainage which can lead to dissolved oxygen reduction, overgrowth of invasive species, and death of fishes (predators of Thiaridae).

Their aggression, rapid reproduction, and growth rate enable them to displace other gastropods from the same place (Jihad & Makawi, 2022), and they dominated streams and were especially abundant downstream of Kageyo dam. Due to its high fecundity, it is seen as invasive in newly disturbed habitats, but is absent in the relatively less disturbed habitats, and is slow to invade water-bodies where the impact of human activities is relatively small (Africa et al., 2014). This reflects the relationship of the presence of this group in my study area, where there was pollution and disturbance due to irrigated agriculture which influenced BMI assemblages in this area.

I have recorded low BMI taxa at the Gatindo site with numerous mayflies (Ephemeroptera) compared to Kageyo and Gatindo sites, Gatindo site was mainly affected by moderate agricultural activities and canals supplying water on upland agricultural sites with the increase of farming activities towards Gatindo dam and Mucucu area. Intensification practices may be the cause of this decline in BMI taxa compared to other sampled sites, including the expansion of farms, cutting down grasses to facilitate mechanization, inorganic materials around dam construction, monocultures, and increasing application of fertilizers and pesticides (Abudulai et al., 2022)**.**

The heavy machinery used for the hydro-technical management and maintenance work with cement to build the canal draining water from Gatindo dam likely related to the absence of BMI individuals downstream observed during high precipitation. The limiting factors of BMI absence at Gatindo downstream were the uniformity of habitats and the limited availability of resources (e.g., food, shelter, substrate) (Popović et al., 2022) influenced by combined watershed management (Fierro et al., 2021a) just beyond the dam site, as a result of use and deposition of inorganic materials and water flow diversion which disturbed the linked substratum (Sharma et al., 2005).

Compared to Kageyo and Gatindo study sites, during this research, I have observed an increase of eutrophication and phytoplankton at the Mucucu site, where there were high livestock activities. Runoff from livestock can reduce light penetration and dissolved oxygen in benthic habitats, and influence the presence of Diptera (Chironomidae) taxa, particularly their red larvae, which possess hemoglobin pigment-fixing oxygen and can survive with anaerobic metabolism. I have also recorded Hirudinidae (leeches) species at this site with reproduction and morphology affected and deteriorated by pesticides and fertilizers used in agriculture but tolerate organic components from excretion of animals (Saglam, 2018)**.** Both were collected at Mucucu where there was high livestock activities; these organisms (Chironomidae and Hirudinidae) take advantage of the absence of large competitors and predators and prefer the area of phytoplankton (Khudhair et al., 2019) induced by the presence of organic nutrients (Nitrate and Phosphorus) due to farming activities (Alavaisha et al., 2019).

The massive livestock presence is associated with organic nutrients driving the large phosphorus and nitrate compositions which can be found in associated wetlands (Saglam, 2018) and this induces the proliferation of the eutrophication process and the disordered growth of phytoplankton including those capable of producing and releasing toxic substances affecting the structure of benthic macroinvertebrates in the water stream (Mello & Abessa, 2021). In this study, the absence of BMI individuals at the Mucucu downstream sample site during low precipitation was likely related with this disturbance. Absence of sensitive Insecta (E P T) and presence of numerous tolerant non Insecta (Mollusca) in sample recorded in locality dominated by agriculture while numerous Insecta individuals with a number of sensitive ones (EPT) were recorded where tolerant BMI (Mollusca) individuals were decreased in area of moderate or absent agriculture activities, this reflection indicated the influences of land use practices on the benthic macroinvertebrates assemblage.

5.3. BMI community and seasons (low and high precipitation)

I have observed that with the activation of irrigation activities, heavy rainfall changes the environmental properties which cause the transport and propagation of higher external pollutant materials (agrochemicals and organic nutrients from animals' excretion) which impact water quality and substrate type. The lower pH recorded in my sample sites directed to the instability and regular change of the substrate (Teristiandi, 2021) which led to a significant decrease in BMI individuals recorded in high precipitation compared to those of low precipitation period. Some BMI taxa (Mollusca) recorded in both periods of precipitation showed resilience to high precipitation and flooding (River et al., 2021).

CONCLUSION AND RECOMMENDATIONS

Freshwater ecosystems particularly wetlands are complex ecosystems ecologically interacting with their host organisms (fauna and flora), and modifications to the system give information about environmental and habitat conditions or health status. Continuing irrigation practices in the areas of agriculture and livestock activities in Kageyo, Gatindo, and Mucucu wetland sites without a deep environment impact assessment and regular monitoring in such areas vulnerable to the long dry season, especially with climate change impacts, can trigger serious environmental problems such as water scarcity, soil desiccation and cracking, extinction of aquatic species (fauna and flora), floods, eutrophication, and proliferation of invasive species. These have impacts not only on wetland ecosystems and the services they provide, but also on nearby ecosystems and human wellbeing.

This research has shown that benthic macroinvertebrates can be used to evaluate the impacts of irrigation on wetlands health in Kageyo, Gatindo, and Mucucu. Results have shown that benthic macroinvertebrates are ecologically affected by wetland conditions; along streams, the strong influence of irrigation activities induced wetland degradation and facilitated pollution propagation throughout the drainage that changed water quality, influenced substrate type, and affected BMI community differently within streams. The great abundance of tolerant taxa (Thiaridae) recorded from downstream and the number of EPT sensitive individuals recorded upstreams indicated the effect of irrigation on downstream than upstreams of the dams so the first and second hypotheses were accepted. Benthic macroinvertebrates are ecologically affected by wetland stream conditions, in this study some sensitive species were absent from the area while others have shown significant community modification (diversity and abundance) according to their level of tolerance and sensitivity to the present pollution and degradation of the habitat.

The results have shown that Thiaridae snails tolerating pollution were abundant in area dominated by agricultural activities mainly Kageyo downsteam with absence of EPT taxa sensitive to pollution while eutrophication, decomposition of organic matter and high level of water turbidity in Mucucu, area dominated by livestock activities influenced the presence of taxa (Chironomidae and Hirudinidae) tolerating very low dissolved oxygen recorded in Mucucu streams. So, the first and second objectives were achieved and the third null hypothesis was rejected while alternative was accepted.

Benthic macroinvertebrates can be used to develop a baseline for monitoring wetland ecosystems' health based on indicator species (sensitive and tolerant) recorded, as this study has shown that fewer EPT were found in disturbed or polluted stream location while numerous individuals with high tolerance (Thiaridae) were present, third objective was achieved.

Irrigation drains water off and decreases its level, especially during the dry period, and this can cause soil desiccation and cracking making these previously wet ecosystems exposed to natural and anthropogenic stressors that lead to negative impacts on the wetland ecosystem value and function, limiting their ability to provide climate change adaptation services. In addition to habitat conditions, benthic macroinvertebrates can also provide information about other organisms in the same ecosystems based on the species presence. As they are an important source of food for other aquatic organisms and they affect the entire food chain (or web) in wetland ecosystems so their absence/presence is ecologically meaningful to wetland health status.

Therefore, this research has shown irrigation and dams effects on the ecosystem health status in three wetland study sites (Kageyo, Gatindo, Mucucu) due to the agriculture and farming activities and other threats (erosion, floods, invasive species) facilitated by irrigation activities in the study areas which cause impacts to benthic macroinvertebrate habitats and communities structure.

To the researchers, authorities, policymakers, project owners, and decision-makers in charge of the environment, I recommend that promoting wetland impact assessment using aquatic organisms before any wetland management and practices as well as follow -up should become a crucial strategy to monitor and mitigate the short or long term impact on such ecosystems function and value. Irrigation systems are a strategy to cope with the problems of drought in sustainable ways when they are effective for both ecosystems and human wellbeing.

Integrated wetland management with its sustainable functions and value requires qualitative and quantitative studies to respond to both human and ecological needs. Effective irrigation with environmental impact assessment followed by ecological monitoring contribute to the solution of both socio-economic issues and wetland ecosystem protection sustainably hence resolving the problem of food security and building the resilience of these fragile ecosystems to climate change. A crucial effort also is needed in protecting neighboring terrestrial ecosystems by maintaining their natural vegetation/forest or planting indigenous species with permanent buffer zones as they contribute to wetland protection.

I also recommend more research in other wetlands more vulnerable to climate change in different areas as a crucial issue for environmental protection for biodiversity conservation and human health security. Other indicators can be used to evaluate not only wetland health but also other ecosystems' health for both human and environmental advantages in sustainable ways.

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APPENDICES

Appendix1: Data collection sheet

Sectors	Seasons	Sites	Location			Plot code	Plot location	Substrate type	BMI (Family taxon)	Abundance
			Latitude	Longitude	Altitude					
Mwiri	High precipitation	Kageyo	239502	9795661	1313	KMP1	Within dam	Washed plant debris	Aechnidae	1
Mwiri	High precipitation	Kageyo	239502	9795661	1313	KMP1	Within dam	Washed plant debris	Libellulidae	2
Mwiri	High precipitation	Kageyo	239502	9795661	1313	KMP1	Within dam	Washed plant debris	Belostomatidae	2
Mwiri	High precipitation	Kageyo	239502	9795661	1313	KMP1	Within dam	Washed plant debris	Ampullaridae	4
Mwiri	High precipitation	Kageyo	238352	9796559	1308	KMP2	Downstream	Mud	Ampullaridae	1
Mwiri	High precipitation	Kageyo	238352	9796559	1308	KMP2	Downstream	Mud	Thiaridae	27
Mwiri	High precipitation	Kageyo	238352	9796559	1308	KMP2	Downstream	Mud	Planorbidae	13
Mwiri	High precipitation	Kageyo	238352	9796559	1308	KMP2	Downstream	Mud	Bulinidae	1
Mwiri	High precipitation	Kageyo	237560	9797801	1300	KMP3	Downstream	Mud and plant debris with floating grasses	Planorbidae	9
Mwiri	High precipitation	Kageyo	237560	9797801	1300	KMP3	Downstream	Mud and plant debris with floating grasses	Bulinidae	3
Mwiri	High precipitation	Kageyo	237560	9797801	1300	KMP3	Downstream	Mud and plant debris with floating grasses	Thiaridae	1
Mwiri	High precipitation	Kageyo	237560	9797801	1300	KMP3	Downstream	Mud and plant debris with floating grasses	Lymnaeidae	4
Mwiri	High precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud and plant debris with floating grasses	Physidae	12
Mwiri	High precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud and plant debris with floating grasses	Hirudinidae	1
Mwiri	High precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud and plant debris with floating grasses	Chironomidae	35
Mwiri	High precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud and plant debris with floating grasses	Ampullaridae	1
Mwiri	High precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud and plant debris with floating grasses	Belostomatidae	1
Mwiri	High precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud and plant debris with floating grasses	Chironomidae	5
Mwiri	High precipitation	Gatindo	237894	9804023	1303	GMP1	Upstream	Washed plant debris	Ampullaridae	1
Mwiri	High precipitation	Gatindo	237894	9804023	1303	GMP1	Upstream	Washed plant debris	Lymnaeidae	1
Mwiri	High precipitation	Gatindo	237894	9804023	1303	GMP1	Upstream	Washed plant debris	Belostomatidae	1
Mwiri	High precipitation	Gatindo	237894	9804023	1303	GMP1	Upstream	Washed plant debris	Planorbidae	1
Mwiri	High precipitation	Gatindo	237894	9804023	1303	GMP1	Upstream	Washed plant debris	Hirudinidae	1

Mwiri	High precipitation	Gatindo	237894	9804023	1303	GMP1	Upstream	Washed plant debris	Chironomidae	2
Mwiri	High precipitation	Gatindo	237894	9804023	1303	GMP1	Upstream	Washed plant debris	Hydrophilidae	1
Mwiri	High precipitation	Gatindo	239169	9804638	1300	GMP2	Upstream	Plant debris with floating plants	Bulinidae	5
Mwiri	High precipitation	Gatindo	239169	9804638	1300	GMP2	Upstream	Plant debris with floating plants	Lymnaeidae	2
Mwiri	High precipitation	Gatindo	239169	9804638	1300	GMP2	Upstream	Plant debris with floating plants	Belostomatidae	2
Mwiri	High precipitation	Gatindo	239169	9804638	1300	GMP2	Upstream	Plant debris with floating plants	Ampullaridae	1
Mwiri	High precipitation	Gatindo	239169	9804638	1300	GMP2	Upstream	Plant debris with floating plants	Tateidae	2
Mwiri	High precipitation	Gatindo	239169	9804638	1300	GMP2	Upstream	Plant debris with floating plants	Chironomidae	3
Mwiri	High precipitation	Gatindo	239169	9804638	1300	GMP2	Upstream	Plant debris with floating plants	Unionidae	1
Mwiri	High precipitation	Gatindo	239174	9806062	1299	GMP3	Within dam	Washed plant debris with floating plants	Belostomatidae	2
Mwiri	High precipitation	Gatindo	239174	9806062	1299	GMP3	Within dam	Washed plant debris with floating plants	Lymnaeidae	1
Mwiri	High precipitation	Gatindo	239088	9806188	1299	GMP4	Upstream	Mud with plant debris	Lymnaeidae	5
Mwiri	High precipitation	Gatindo	239088	9806188	1299	GMP4	Upstream	Mud with plant debris	Libellulidae	1
Mwiri	High precipitation	Gatindo	239088	9806188	1299	GMP4	Upstream	Mud with plant debris	Belostomatidae	1
Mwiri	High precipitation	Gatindo	239088	9806188	1299	GMP4	Upstream	Mud with plant debris	Coenagrionidae	1
Mwiri	High precipitation	Gatindo	239088	9806188	1299	GMP4	Upstream	Mud with plant debris	Bulinidae	1
Mwiri	High precipitation	Gatindo	239176	9806188	1299	GMP5	Downstream	-	No BMI	0
Murundi	High precipitation	Mucucu	234558	9814940	1294	MMP1	Upstream	Floating plant debris	Belostomatidae	5
Murundi	High precipitation	Mucucu	234558	9814940	1294	MMP1	Upstream	Floating plant debris	Dytiscidae	2
Murundi	High precipitation	Mucucu	234558	9814940	1294	MMP1	Upstream	Floating plant debris	Hydrophilidae	1
Murundi	High precipitation	Mucucu	233311	9816235	1307	MMP2	Upstream	Floating plants	Dytiscidae	1
Murundi	High precipitation	Mucucu	233311	9816235	1307	MMP2	Upstream	Floating plants	Planorbidae	1
Murundi	High precipitation	Mucucu	233311	9816235	1307	MMP2	Upstream	Floating plants	Belostomatidae	4
Murundi	High precipitation	Mucucu	233311	9816235	1307	MMP2	Upstream	Floating plants	Hydrophilidae	1
Murundi	High precipitation	Mucucu	232541	9817878	1289	MMP3 (Left)	Within dam	Soil and plant debris	Hirudinidae	3
Murundi	High precipitation	Mucucu	232541	9817878	1289	MMP3 (Left)	Within dam	Soil and plant debris	Ampullaridae	5
Murundi	High precipitation	Mucucu	232541	9817878	1289	MMP3 (Left)	Within dam	Soil and plant debris	Belostomatidae	2
Murundi	High precipitation	Mucucu	232541	9817878	1289	MMP3 (Left)	Within dam	Soil and plant debris	Dytiscidae	1

Murundi	High precipitation	Mucucu	232541	9817878	1289	MMP3 (Left)	Within dam	Soil and plant debris	Bulinidae	7
Murundi	High precipitation	Mucucu	232541	9817878	1289	MMP3 (Left)	Within dam	Soil and plant debris	Lymnaeidae	1
Murundi	High precipitation	Mucucu	232116	9817938	1285	MMP4 (Right)	Within dam	Soil and decayed plant debris	Libellulidae	3
Murundi	High precipitation	Mucucu	232116	9817938	1285	MMP4 (Right)	Within dam	Soil and decayed plant debris	Hirudinidae	2
Murundi	High precipitation	Mucucu	232116	9817938	1285	MMP4 (Right)	Within dam	Soil and decayed plant debris	Chironomidae	10
Murundi	High precipitation	Mucucu	232043	9817830	1294	MMP5	Downstream	Mud with plant debris	Belostomatidae	4
Murundi	High precipitation	Mucucu	232043	9817830	1294	MMP5	Downstream	Mud with plant debris	Hydrophilidae	5
Murundi	High precipitation	Mucucu	232043	9817830	1294	MMP5	Downstream	Mud with plant debris	Hirudinidae	1
Murundi	High precipitation	Mucucu	232043	9817830	1294	MMP5	Downstream	Mud with plant debris	Libellulidae	1
Murundi	High precipitation	Mucucu	232043	9817830	1294	MMP5	Downstream	Mud with plant debris	Tipulidae	1
Murundi	High precipitation	Mucucu	232043	9817830	1294	MMP5	Downstream	Mud with plant debris	Ampullaridae	1
Murundi	High precipitation	Mucucu	232043	9817830	1294	MMP5	Downstream	Mud with plant debris	Limnichidae	2
Murundi	High precipitation	Mucucu	232043	9817830	1294	MMP5	Downstream	Mud with plant debris	Conoesucidae	1
Mwiri	Low precipitation	Kageyo	239502	9795661	1313	KMP1	Within dam	Submerged and sediment plant debris	Belostomatidae	2
Mwiri	Low precipitation	Kageyo	239502	9795661	1313	KMP1	Within dam	Submerged and sediment plant debris	Ampullaridae	8
Mwiri	Low precipitation	Kageyo	239502	9795661	1313	KMP1	Within dam	Submerged and sediment plant debris	Hydrophilidae	2
Mwiri	Low precipitation	Kageyo	239502	9795661	1313	KMP1	Within dam	Submerged and sediment plant debris	Chironomidae	4
Mwiri	Low precipitation	Kageyo	239502	9795661	1313	KMP1	Within dam	Submerged and sediment plant debris	Coenagrionidae	2
Mwiri	Low precipitation	Kageyo	239502	9795661	1313	KMP1	Within dam	Submerged and sediment plant debris	Belostomatidae	3
Mwiri	Low precipitation	Kageyo	238352	9796559	1300	KMP2	Downstream	Mud	Coenagrionidae	4
Mwiri	Low precipitation	Kageyo	238352	9796559	1300	KMP2	Downstream	Mud	Simuriidae	2
Mwiri	Low precipitation	Kageyo	238352	9796559	1300	KMP2	Downstream	Mud	Belostomatidae	5
Mwiri	Low precipitation	Kageyo	238352	9796559	1300	KMP2	Downstream	Mud	Lymnaeidae	1
Mwiri	Low precipitation	Kageyo	238352	9796559	1300	KMP2	Downstream	Mud	Physidae	7
Mwiri	Low precipitation	Kageyo	238352	9796559	1300	KMP2	Downstream	Mud	Planorbidae	8
Mwiri	Low precipitation	Kageyo	238352	9796559	1300	KMP2	Downstream	Mud	Physidae	2
Mwiri	Low precipitation	Kageyo	238352	9796559	1308	KMP2	Downstream	Mud	Bulinidae	3
Mwiri	Low precipitation	Kageyo	237560	9797801	1300	KMP3	Downstream	Mud	Lymnaeidae	2

Mwiri	Low precipitation	Kageyo	237560	9797801	1300	KMP3	Downstream	Mud	Physidae	4
Mwiri	Low precipitation	Kageyo	237560	9797801	1300	KMP3	Downstream	Mud	Planorbidae	37
Mwiri	Low precipitation	Kageyo	237560	9797801	1300	KMP3	Downstream	Mud	Thiaridae	357
Mwiri	Low precipitation	Kageyo	237560	9797801	1300	KMP3	Downstream	Mud	Physidae	11
Mwiri	Low precipitation	Kageyo	237560	9797801	1300	KMP3	Downstream	Mud	Lymnaeidae	3
Mwiri	Low precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud	Belostomatidae	2
Mwiri	Low precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud	Lymnaeidae	13
Mwiri	Low precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud	Dytiscidae	6
Mwiri	Low precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud	Physidae	14
Mwiri	Low precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud	Planorbidae	34
Mwiri	Low precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud	Thiaridae	12
Mwiri	Low precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud	Physidae	15
Mwiri	Low precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud	Physidae	1
Mwiri	Low precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud	Ampullaridae	5
Mwiri	Low precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud	Hydrophilidae	1
Mwiri	Low precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud	Belostomatidae	2
Mwiri	Low precipitation	Kageyo	237448	9800547	1300	KMP4	Downstream	Mud	Unionidae	7
Mwiri	Low precipitation	Gatindo	237894	9804023	1303	GMP1	Upstream	Flooded soil with emergent grasses	Belostomatidae	26
Mwiri	Low precipitation	Gatindo	237894	9804023	1303	GMP1	Upstream	Flooded soil with emergent grasses	Planorbidae	1
Mwiri	Low precipitation	Gatindo	237894	9804023	1303	GMP1	Upstream	Flooded soil with emergent grasses	Hydrophilidae	1
Mwiri	Low precipitation	Gatindo	237894	9804023	1303	GMP1	Upstream	Flooded soil with emergent grasses	Dytiscidae	1
Mwiri	Low precipitation	Gatindo	237894	9804023	1303	GMP1	Upstream	Flooded soil with emergent grasses	Unidentified mayflies	10
Mwiri	Low precipitation	Gatindo	237894	9804023	1303	GMP1	Upstream	Flooded soil with emergent grasses	Simuriidae	1
Mwiri	Low precipitation	Gatindo	239169	9804638	1300	GMP2	Upstream	Flooded soil	Belostomatidae	3
Mwiri	Low precipitation	Gatindo	239169	9804638	1300	GMP2	Upstream	Flooded soil	Dytiscidae	1
Mwiri	Low precipitation	Gatindo	239169	9804638	1300	GMP2	Upstream	Flooded soil	Ampullaridae	1
Mwiri	Low precipitation	Gatindo	239169	9804638	1300	GMP2	Upstream	Flooded soil	Hydrophilidae	28
Mwiri	Low precipitation	Gatindo	239169	9804638	1300	GMP2	Upstream	Flooded soil	Chironomidae	4
Mwiri	Low precipitation	Gatindo	239169	9804638	1300	GMP2	Upstream	Flooded soil	Unidentified mayflies	4

Mwiri	Low precipitation	Gatindo	239174	9806062	1299	GMP3	Within dam	Marginal suspended and emergent grasses	Belostomatidae	40
Mwiri	Low precipitation	Gatindo	239174	9806062	1299	GMP3	Within dam	Marginal suspended and emergent grasses	Lymnaeidae	6
Mwiri	Low precipitation	Gatindo	239174	9806062	1299	GMP3	Within dam	Marginal suspended and emergent grasses	Dytiscidae	2
Mwiri	Low precipitation	Gatindo	239174	9806062	1299	GMP3	Within dam	Marginal suspended and emergent grasses	Planorbidae	3
Mwiri	Low precipitation	Gatindo	239174	9806062	1299	GMP3	Within dam	Marginal suspended and emergent grasses	Bulinidae	1
Mwiri	Low precipitation	Gatindo	239174	9806062	1299	GMP3	Within dam	Marginal suspended and emergent grasses	Dytiscidae	4
Mwiri	Low precipitation	Gatindo	239174	9806062	1299	GMP3	Within dam	Marginal suspended and emergent grasses	Dytiscidae	2
Mwiri	Low precipitation	Gatindo	239174	9806062	1299	GMP3	Within dam	Marginal suspended and emergent grasses	Hydrophilidae	10
Mwiri	Low precipitation	Gatindo	239174	9806062	1299	GMP3	Within dam	Marginal suspended and emergent grasses	Chironomidae	4
Mwiri	Low precipitation	Gatindo	239174	9806062	1299	GMP3	Within dam	Marginal suspended and emergent grasses	Hydrophilidae	30
Mwiri	Low precipitation	Gatindo	239088	9805535	1301	GMP4	Upstream	Flooded soil with emergent grasses	Belostomatidae	20
Mwiri	Low precipitation	Gatindo	239088	9805535	1301	GMP4	Upstream	Flooded soil with emergent grasses	Lymnaeidae	9
Mwiri	Low precipitation	Gatindo	239088	9805535	1301	GMP4	Upstream	Flooded soil with emergent grasses	Planorbidae	1
Mwiri	Low precipitation	Gatindo	239088	9805535	1301	GMP4	Upstream	Flooded soil with emergent grasses	Planorbidae	2
Mwiri	Low precipitation	Gatindo	239088	9805535	1301	GMP4	Upstream	Flooded soil with emergent grasses	Bulinidae	1
Mwiri	Low precipitation	Gatindo	239088	9805535	1301	GMP4	Upstream	Flooded soil with emergent grasses	Hydrophilidae	2
Mwiri	Low precipitation	Gatindo	239088	9805535	1301	GMP4	Upstream	Flooded soil with emergent grasses	Dytiscidae	1
Mwiri	Low precipitation	Gatindo	239088	9805535	1301	GMP4	Upstream	Flooded soil with emergent grasses	Dytiscidae	1

Mwiri	Low precipitation	Gatindo	239088	9805535	1301	GMP4	Upstream	Flooded soil with emergent grasses	Bulinidae	2
Mwiri	Low precipitation	Gatindo	239088	9805535	1301	GMP4	Upstream	Flooded soil with emergent grasses	Ampullaridae	2
Mwiri	Low precipitation	Gatindo	239088	9805535	1301	GMP4	Upstream	Flooded soil with emergent grasses	Hydrophilidae	2
Mwiri	Low precipitation	Gatindo	239088	9805535	1301	GMP4	Upstream	Flooded soil with emergent grasses	Chironomidae	2
Mwiri	Low precipitation	Gatindo	239088	9805535	1301	GMP4	Upstream	Flooded soil with emergent grasses	Hydrophilidae	7
Mwiri	Low precipitation	Gatindo	239176	9806188	1299	GMP5	Downstream	Mud	Belostomatidae	1
Murundi	Low precipitation	Mucucu	234558	9814940	1294	MMP1	Upstream	Mud and decaying plant debris	Belostomatidae	4
Murundi	Low precipitation	Mucucu	234558	9814940	1294	MMP1	Upstream	Mud and decaying plant debris	Lymnaeidae	1
Murundi	Low precipitation	Mucucu	234558	9814940	1294	MMP1	Upstream	Mud and decaying plant debris	Planorbidae	4
Murundi	Low precipitation	Mucucu	234558	9814940	1294	MMP1	Upstream	Mud and decaying plant debris	Hydrophilidae	8
Murundi	Low precipitation	Mucucu	234558	9814940	1294	MMP1	Upstream	Mud and decaying plant debris	Dytiscidae	1
Murundi	Low precipitation	Mucucu	234558	9814940	1294	MMP1	Upstream	Mud and decaying plant debris	Hydrophilidae	3
Murundi	Low precipitation	Mucucu	234558	9814940	1294	MMP1	Upstream	Mud and decaying plant debris	Chironomidae	46
Murundi	Low precipitation	Mucucu	234558	9814940	1294	MMP1	Upstream	Mud and decaying plant debris	Unidentified mayflies	1
Murundi	Low precipitation	Mucucu	234558	9814940	1294	MMP1	Upstream	Mud and decaying plant debris	Ampullaridae	1
Murundi	Low precipitation	Mucucu	234558	9814940	1294	MMP1	Upstream	Mud and decaying plant debris	Belostomatidae	3
Murundi	Low precipitation	Mucucu	233311	9816235	1307	MMP2	Upstream	Mud and decaying plant debris	Belostomatidae	2
Murundi	Low precipitation	Mucucu	233311	9816235	1307	MMP2	Upstream	Mud and decaying plant debris	Lymnaeidae	1
Murundi	Low precipitation	Mucucu	233311	9816235	1307	MMP2	Upstream	Mud and decaying plant debris	Planorbidae	2
Murundi	Low precipitation	Mucucu	233311	9816235	1307	MMP2	Upstream	Mud and decaying plant debris	Physidae	1
Murundi	Low precipitation	Mucucu	233311	9816235	1307	MMP2	Upstream	Mud and decaying plant debris	Hydrophilidae	5
Murundi	Low precipitation	Mucucu	233311	9816235	1307	MMP2	Upstream	Mud and decaying plant debris	Belostomatidae	1

Murundi	Low precipitation	Mucucu	233311	9816235	1307	MMP2	Upstream	Mud and decaying plant debris	Chironomidae	5
Murundi	Low precipitation	Mucucu	233311	9816235	1307	MMP2	Upstream	Mud and decaying plant debris	Bulinidae	2
Murundi	Low precipitation	Mucucu	233311	9816235	1307	MMP2	Upstream	Mud and decaying plant debris	Belostomatidae	1
Murundi	Low precipitation	Mucucu	232541	9817878	1289	MMP3 (left)	Within dam	Submerged plant debris and floating grasses	Ampullaridae	7
Murundi	Low precipitation	Mucucu	232541	9817878	1289	MMP3 (left)	Within dam	Submerged plant debris and floating grasses	Belostomatidae	1
Murundi	Low precipitation	Mucucu	232116	9817938	1285	MMP4 (right)	Within dam	Submerged plant debris and floating grasses	Belostomatidae	1
Murundi	Low precipitation	Mucucu	232116	9817938	1285	MMP4 (right)	Within dam	Submerged plant debris and floating grasses	Lymnaeidae	5
Murundi	Low precipitation	Mucucu	232116	9817938	1285	MMP4 (right)	Within dam	Submerged plant debris and floating grasses	Dytiscidae	2
Murundi	Low precipitation	Mucucu	232116	9817938	1285	MMP4(right)	Within dam	Submerged plant debris and floating grasses	Physidae	1
Murundi	Low precipitation	Mucucu	232116	9817938	1285	MMP4 (right)	Within dam	Submerged plant debris and floating grasses	Planorbidae	2
Murundi	Low precipitation	Mucucu	232116	9817938	1285	MMP4 (right)	Within dam	Submerged plant debris and floating grasses	Physidae	4
Murundi	Low precipitation	Mucucu	232116	9817938	1285	MMP4 (right)	Within dam	Submerged plant debris and floating grasses	Bulinidae	1
Murundi	Low precipitation	Mucucu	232116	9817938	1285	MMP4 (right)	Within dam	Submerged plant debris and floating grasses	Nepidae	1
Murundi	Low precipitation	Mucucu	232116	9817938	1285	MMP4 (right)	Within dam	Submerged plant debris and floating grasses	Hydrophilidae	2
Murundi	Low precipitation	Mucucu	232116	9817938	1285	MMP4 (right)	Within dam	Submerged plant debris and floating grasses	Belostomatidae	2
Murundi	Low precipitation	Mucucu	232116	9817938	1285	MMP4 (right)	Within dam	Submerged plant debris and floating grasses	Belostomatidae	3
Murundi	Low precipitation	Mucucu	232116	9817938	1285	MMP4 (right)	Within dam	Submerged plant debris and floating grasses	Nepidae	5
Murundi	Low precipitation	Mucucu	232043	9817830	1294	MMP5	Downstream	Submerged plant debris and floating grasses	No BMI	0

Appendix 2: Water quality parameters

Seasons	Sites	Plot code	Plot location	Water quality in high precipitation						
				Dissolved oxygen	Biochemical oxygen demand	Total Dissolved Solid	PH	Tº	Conductivity	Turbidity
High precipitation	Kageyo	KMP1	Within dam	8.61	29.13	154.4	7.85	26.9	359	30.7
High precipitation	Kageyo	KMP1	Within dam	8.61	29.13	154.4	7.85	26.9	359	30.7
High precipitation	Kageyo	KMP1	Within dam	8.61	29.13	154.4	7.85	26.9	359	30.7
High precipitation	Kageyo	KMP1	Within dam	8.61	29.13	154.4	7.85	26.9	359	30.7
High precipitation	Kageyo	KMP2	Downstream	4.69	14.28	163.4	6.82	25	343	44.3
High precipitation	Kageyo	KMP2	Downstream	4.69	14.28	163.4	6.82	25	343	44.3
High precipitation	Kageyo	KMP2	Downstream	4.69	14.28	163.4	6.82	25	343	44.3
High precipitation	Kageyo	KMP2	Downstream	4.69	14.28	163.4	6.82	25	343	44.3
High precipitation	Kageyo	KMP3	Downstream	1.85	28.53	185.6	6.91	30.5	433	12.9
High precipitation	Kageyo	KMP3	Downstream	1.85	28.53	185.6	6.91	30.5	433	12.9
High precipitation	Kageyo	KMP3	Downstream	1.85	28.53	185.6	6.91	30.5	433	12.9
High precipitation	Kageyo	KMP3	Downstream	1.85	28.53	185.6	6.91	30.5	433	12.9
High precipitation	Kageyo	KMP4	Downstream	1.91	23.13	168.7	6.57	24.3	353	27.9
High precipitation	Kageyo	KMP4	Downstream	1.91	23.13	168.7	6.57	24.3	353	27.9
High precipitation	Kageyo	KMP4	Downstream	1.91	23.13	168.7	6.57	24.3	353	27.9

High precipitation	Kageyo	KMP4	Downstream	1.91	23.13	168.7	6.57	24.3	353	27.9
High precipitation	Kageyo	KMP4	Downstream	1.91	23.13	168.7	6.57	24.3	353	27.9
High precipitation	Kageyo	KMP4	Downstream	1.91	23.13	168.7	6.57	24.3	353	27.9
High precipitation	Gatindo	GMP1	Upstream	0.62	23.73	165.8	6.84	24.6	345	9.95
High precipitation	Gatindo	GMP1	Upstream	0.62	23.73	165.8	6.84	24.6	345	9.95
High precipitation	Gatindo	GMP1	Upstream	0.62	23.73	165.8	6.84	24.6	345	9.95
High precipitation	Gatindo	GMP1	Upstream	0.62	23.73	165.8	6.84	24.6	345	9.95
High precipitation	Gatindo	GMP1	Upstream	0.62	23.73	165.8	6.84	24.6	345	9.95
High precipitation	Gatindo	GMP1	Upstream	0.62	23.73	165.8	6.84	24.6	345	9.95
High precipitation	Gatindo	GMP1	Upstream	0.62	23.73	165.8	6.84	24.6	345	9.95
High precipitation	Gatindo	GMP2	Upstream	2.10	23.13	162.8	6.6	24.8	347	20.5
High precipitation	Gatindo	GMP2	Upstream	2.10	23.13	162.8	6.6	24.8	347	20.5
High precipitation	Gatindo	GMP2	Upstream	2.10	23.13	162.8	6.6	24.8	347	20.5
High precipitation	Gatindo	GMP2	Upstream	2.10	23.13	162.8	6.6	24.8	347	20.5
High precipitation	Gatindo	GMP2	Upstream	2.10	23.13	162.8	6.6	24.8	347	20.5
High precipitation	Gatindo	GMP2	Upstream	2.10	23.13	162.8	6.6	24.8	347	20.5
High precipitation	Gatindo	GMP2	Upstream	2.10	23.13	162.8	6.6	24.8	347	20.5
High precipitation	Gatindo	GMP3	Within dam	5.02	19.23	152.7	6.9	25.2	324	18.2

High precipitation	Gatindo	GMP3	Within dam	5.02	19.23	152.7	6.9	25.2	324	18.2
High precipitation	Gatindo	GMP4	Upstream	2.34	22.83	130.8	6.89	25.6	279	11.2
High precipitation	Gatindo	GMP4	Upstream	2.34	22.83	130.8	6.89	25.6	279	11.2
High precipitation	Gatindo	GMP4	Upstream	2.34	22.83	130.8	6.89	25.6	279	11.2
High precipitation	Gatindo	GMP4	Upstream	2.34	22.83	130.8	6.89	25.6	279	11.2
High precipitation	Gatindo	GMP4	Upstream	2.34	22.83	130.8	6.89	25.6	279	11.2
High precipitation	Mucucu	MMP1	Upstream	0.70	24.18	203.2	7	25	426	39.0
High precipitation	Mucucu	MMP1	Upstream	0.70	24.18	203.2	7	25	426	39.0
High precipitation	Mucucu	MMP1	Upstream	0.70	24.18	203.2	7	25	426	39.0
High precipitation	Mucucu	MMP2	Upstream	4.42	9.88	160.2	6.83	23	341	9.44
High precipitation	Mucucu	MMP2	Upstream	4.42	9.88	160.2	6.83	23	341	9.44
High precipitation	Mucucu	MMP2	Upstream	4.42	9.88	160.2	6.83	23	341	9.44
High precipitation	Mucucu	MMP2	Upstream	4.42	9.88	160.2	6.83	23	341	9.44
High precipitation	Mucucu	MMP3 (Left)	Within dam	1.2	15.18	238	6.65	23.8	485	42.2
High precipitation	Mucucu	MMP3 (Left)	Within dam	1.2	15.18	238	6.65	23.8	485	42.2
High precipitation	Mucucu	MMP3 (Left)	Within dam	1.2	15.18	238	6.65	23.8	485	42.2
High precipitation	Mucucu	MMP3 (Left)	Within dam	1.2	15.18	238	6.65	23.8	485	42.2
High precipitation	Mucucu	MMP3 (Left)	Within dam	1.2	15.18	238	6.65	23.8	485	42.2

High precipitation	Mucucu	MMP3 (Left)	Within dam	1.2	15.18	238	6.65	23.8	485	42.2
High precipitation	Mucucu	MMP4 (Right)	Within dam	2.66	14.73	232	6.72	25.6	489	30.9
High precipitation	Mucucu	MMP4 (Right)	Within dam	2.66	14.73	232	6.72	25.6	489	30.9
High precipitation	Mucucu	MMP4 (Right)	Within dam	2.66	14.73	232	6.72	25.6	489	30.9
High precipitation	Mucucu	MMP5	Downstream	0.87	4.08	230	6.77	22.4	464	15.5
High precipitation	Mucucu	MMP5	Downstream	0.87	4.08	230	6.77	22.4	464	15.5
High precipitation	Mucucu	MMP5	Downstream	0.87	4.08	230	6.77	22.4	464	15.5
High precipitation	Mucucu	MMP5	Downstream	0.87	4.08	230	6.77	22.4	464	15.5
High precipitation	Mucucu	MMP5	Downstream	0.87	4.08	230	6.77	22.4	464	15.5
High precipitation	Mucucu	MMP5	Downstream	0.87	4.08	230	6.77	22.4	464	15.5
High precipitation	Mucucu	MMP5	Downstream	0.87	4.08	230	6.77	22.4	464	15.5
High precipitation	Mucucu	MMP5	Downstream	0.87	4.08	230	6.77	22.4	464	15.5
Low precipitation	Kageyo	KMP1	Within dam	0.40	17.1	283	7.94	27.2	623	18.4
Low precipitation	Kageyo	KMP1	Within dam	0.40	17.1	283	7.94	27.2	623	18.4
Low precipitation	Kageyo	KMP1	Within dam	0.40	17.1	283	7.94	27.2	623	18.4
Low precipitation	Kageyo	KMP1	Within dam	0.40	17.1	283	7.94	27.2	623	18.4
Low precipitation	Kageyo	KMP1	Within dam	0.40	17.1	283	7.94	27.2	623	18.4
Low precipitation	Kageyo	KMP1	Within dam	0.40	17.1	283	7.94	27.2	623	18.4

Low precipitation	Kageyo	KMP2	Downstream	3.84	21.3	299	8.37	30	683	18.2
Low precipitation	Kageyo	KMP2	Downstream	3.84	21.3	299	8.37	30	683	18.2
Low precipitation	Kageyo	KMP2	Downstream	3.84	21.3	299	8.37	30	683	18.2
Low precipitation	Kageyo	KMP2	Downstream	3.84	21.3	299	8.37	30	683	18.2
Low precipitation	Kageyo	KMP2	Downstream	3.84	21.3	299	8.37	30	683	18.2
Low precipitation	Kageyo	KMP2	Downstream	3.84	21.3	299	8.37	30	683	18.2
Low precipitation	Kageyo	KMP2	Downstream	3.84	21.3	299	8.37	30	683	18.2
Low precipitation	Kageyo	KMP2	Downstream	3.84	21.3	299	8.37	30	683	18.2
Low precipitation	Kageyo	KMP3	Downstream	7.07	6.9	180.7	7.65	32.9	439	91.7
Low precipitation	Kageyo	KMP3	Downstream	7.07	6.9	180.7	7.65	32.9	439	91.7
Low precipitation	Kageyo	KMP3	Downstream	7.07	6.9	180.7	7.65	32.9	439	91.7
Low precipitation	Kageyo	KMP3	Downstream	7.07	6.9	180.7	7.65	32.9	439	91.7
Low precipitation	Kageyo	KMP3	Downstream	7.07	6.9	180.7	7.65	32.9	439	91.7
Low precipitation	Kageyo	KMP3	Downstream	7.07	6.9	180.7	7.65	32.9	439	91.7
Low precipitation	Kageyo	KMP4	Downstream	3.36	0.6	248	6.42	22.1	489	62.9
Low precipitation	Kageyo	KMP4	Downstream	3.36	0.6	248	6.42	22.1	489	62.9
Low precipitation	Kageyo	KMP4	Downstream	3.36	0.6	248	6.42	22.1	489	62.9
Low precipitation	Kageyo	KMP4	Downstream	3.36	0.6	248	6.42	22.1	489	62.9

Low precipitation	Kageyo	KMP4	Downstream	3.36	0.6	248	6.42	22.1	489	62.9
Low precipitation	Kageyo	KMP4	Downstream	3.36	0.6	248	6.42	22.1	489	62.9
Low precipitation	Kageyo	KMP4	Downstream	3.36	0.6	248	6.42	22.1	489	62.9
Low precipitation	Kageyo	KMP4	Downstream	3.36	0.6	248	6.42	22.1	489	62.9
Low precipitation	Kageyo	KMP4	Downstream	3.36	0.6	248	6.42	22.1	489	62.9
Low precipitation	Kageyo	KMP4	Downstream	3.36	0.6	248	6.42	22.1	489	62.9
Low precipitation	Kageyo	KMP4	Downstream	3.36	0.6	248	6.42	22.1	489	62.9
Low precipitation	Kageyo	KMP4	Downstream	3.36	0.6	248	6.42	22.1	489	62.9
Low precipitation	Gatindo	GMP1	Upstream	2.9	5.4	344	6.19	27.2	748	36.3
Low precipitation	Gatindo	GMP1	Upstream	2.9	5.4	344	6.19	27.2	748	36.3
Low precipitation	Gatindo	GMP1	Upstream	2.9	5.4	344	6.19	27.2	748	36.3
Low precipitation	Gatindo	GMP1	Upstream	2.9	5.4	344	6.19	27.2	748	36.3
Low precipitation	Gatindo	GMP1	Upstream	2.9	5.4	344	6.19	27.2	748	36.3
Low precipitation	Gatindo	GMP1	Upstream	2.9	5.4	344	6.19	27.2	748	36.3
Low precipitation	Gatindo	GMP2	Upstream	2.08	6.6	327	6.46	30	744	37.9
Low precipitation	Gatindo	GMP2	Upstream	2.08	6.6	327	6.46	30	744	37.9
Low precipitation	Gatindo	GMP2	Upstream	2.08	6.6	327	6.46	30	744	37.9
Low precipitation	Gatindo	GMP2	Upstream	2.08	6.6	327	6.46	30	744	37.9

Low precipitation	Gatindo	GMP2	Upstream	2.08	6.6	327	6.46	30	744	37.9
Low precipitation	Gatindo	GMP2	Upstream	2.08	6.6	327	6.46	30	744	37.9
Low precipitation	Gatindo	GMP3	Within dam	3.71	10.2	417	6.48	29.7	947	37.2
Low precipitation	Gatindo	GMP3	Within dam	3.71	10.2	417	6.48	29.7	947	37.2
Low precipitation	Gatindo	GMP3	Within dam	3.71	10.2	417	6.48	29.7	947	37.2
Low precipitation	Gatindo	GMP3	Within dam	3.71	10.2	417	6.48	29.7	947	37.2
Low precipitation	Gatindo	GMP3	Within dam	3.71	10.2	417	6.48	29.7	947	37.2
Low precipitation	Gatindo	GMP3	Within dam	3.71	10.2	417	6.48	29.7	947	37.2
Low precipitation	Gatindo	GMP3	Within dam	3.71	10.2	417	6.48	29.7	947	37.2
Low precipitation	Gatindo	GMP3	Within dam	3.71	10.2	417	6.48	29.7	947	37.2
Low precipitation	Gatindo	GMP3	Within dam	3.71	10.2	417	6.48	29.7	947	37.2
Low precipitation	Gatindo	GMP3	Within dam	3.71	10.2	417	6.48	29.7	947	37.2
Low precipitation	Gatindo	GMP4	Upstream	2.33	2.4	326	6.42	31.1	763	20.1
Low precipitation	Gatindo	GMP4	Upstream	2.33	2.4	326	6.42	31.1	763	20.1
Low precipitation	Gatindo	GMP4	Upstream	2.33	2.4	326	6.42	31.1	763	20.1
Low precipitation	Gatindo	GMP4	Upstream	2.33	2.4	326	6.42	31.1	763	20.1
Low precipitation	Gatindo	GMP4	Upstream	2.33	2.4	326	6.42	31.1	763	20.1
Low precipitation	Gatindo	GMP4	Upstream	2.33	2.4	326	6.42	31.1	763	20.1

Low precipitation	Gatindo	GMP4	Upstream	2.33	2.4	326	6.42	31.1	763	20.1
Low precipitation	Gatindo	GMP4	Upstream	2.33	2.4	326	6.42	31.1	763	20.1
Low precipitation	Gatindo	GMP4	Upstream	2.33	2.4	326	6.42	31.1	763	20.1
Low precipitation	Gatindo	GMP4	Upstream	2.33	2.4	326	6.42	31.1	763	20.1
Low precipitation	Gatindo	GMP4	Upstream	2.33	2.4	326	6.42	31.1	763	20.1
Low precipitation	Gatindo	GMP4	Upstream	2.33	2.4	326	6.42	31.1	763	20.1
Low precipitation	Gatindo	GMP4	Upstream	2.33	2.4	326	6.42	31.1	763	20.1
Low precipitation	Gatindo	GMP5	Downstream	2.87	40.2	389	6.43	28.8	872	73.2
Low precipitation	Mucucu	MMP1	Upstream	0.14	1.8	344	6.35	21.8	698	13.9
Low precipitation	Mucucu	MMP1	Upstream	0.14	1.8	344	6.35	21.8	698	13.9
Low precipitation	Mucucu	MMP1	Upstream	0.14	1.8	344	6.35	21.8	698	13.9
Low precipitation	Mucucu	MMP1	Upstream	0.14	1.8	344	6.35	21.8	698	13.9
Low precipitation	Mucucu	MMP1	Upstream	0.14	1.8	344	6.35	21.8	698	13.9
Low precipitation	Mucucu	MMP1	Upstream	0.14	1.8	344	6.35	21.8	698	13.9
Low precipitation	Mucucu	MMP1	Upstream	0.14	1.8	344	6.35	21.8	698	13.9
Low precipitation	Mucucu	MMP1	Upstream	0.14	1.8	344	6.35	21.8	698	13.9
Low precipitation	Mucucu	MMP1	Upstream	0.14	1.8	344	6.35	21.8	698	13.9
Low precipitation	Mucucu	MMP1	Upstream	0.14	1.8	344	6.35	21.8	698	13.9

Low precipitation	Mucucu	MMP2	Upstream	0.54	11.4	265	6.31	29.6	608	26.1
Low precipitation	Mucucu	MMP2	Upstream	0.54	11.4	265	6.31	29.6	608	26.1
Low precipitation	Mucucu	MMP2	Upstream	0.54	11.4	265	6.31	29.6	608	26.1
Low precipitation	Mucucu	MMP2	Upstream	0.54	11.4	265	6.31	29.6	608	26.1
Low precipitation	Mucucu	MMP2	Upstream	0.54	11.4	265	6.31	29.6	608	26.1
Low precipitation	Mucucu	MMP2	Upstream	0.54	11.4	265	6.31	29.6	608	26.1
Low precipitation	Mucucu	MMP2	Upstream	0.54	11.4	265	6.31	29.6	608	26.1
Low precipitation	Mucucu	MMP2	Upstream	0.54	11.4	265	6.31	29.6	608	26.1
Low precipitation	Mucucu	MMP2	Upstream	0.54	11.4	265	6.31	29.6	608	26.1
Low precipitation	Mucucu	MMP3(left)	Within dam	7.21	14.7	299	7.39	28.1	511	10.4
Low precipitation	Mucucu	MMP3(left)	Within dam	7.21	14.7	299	7.39	28.1	511	10.4
Low precipitation	Mucucu	MMP4(right)	Within dam	4.96	2.4	232	6.76	28.1	518	11.0
Low precipitation	Mucucu	MMP4(right)	Within dam	4.96	2.4	232	6.76	28.1	518	11.0
Low precipitation	Mucucu	MMP4(right)	Within dam	4.96	2.4	232	6.76	28.1	518	11.0
Low precipitation	Mucucu	MMP4(right)	Within dam	4.96	2.4	232	6.76	28.1	518	11.0
Low precipitation	Mucucu	MMP4(right)	Within dam	4.96	2.4	232	6.76	28.1	518	11.0
Low precipitation	Mucucu	MMP4(right)	Within dam	4.96	2.4	232	6.76	28.1	518	11.0
Low precipitation	Mucucu	MMP4(right)	Within dam	4.96	2.4	232	6.76	28.1	518	11.0

Low precipitation	Mucucu	MMP4(right)	Within dam	4.96	2.4	232	6.76	28.1	518	11.0
Low precipitation	Mucucu	MMP4(right)	Within dam	4.96	2.4	232	6.76	28.1	518	11.0
Low precipitation	Mucucu	MMP4(right)	Within dam	4.96	2.4	232	6.76	28.1	518	11.0
Low precipitation	Mucucu	MMP4(right)	Within dam	4.96	2.4	232	6.76	28.1	518	11.0
Low precipitation	Mucucu	MMP4(right)	Within dam	4.96	2.4	232	6.76	28.1	518	11.0

Appendix 3. Distribution of BMI taxa in the substrate

Substrate		Ampullaridae	Belostomatidae	Bulinidae	Chironomidae	Coenagrionidae	Conoesucidae	Dytiscidae	Hirudinidae	Hydrophilidae	Libellulidae	Limnichidae	Lymnaeidae	Nepidae	Physidae	Planorbidae	Simuriidae	Tateidae	Thiaridae	Tipulidae	Unidentified mayflies	Unionidae
Plant debris with floating grasses		√	√	√	√								√					√				√
Submerged plant debris and floating grasses		√	√	√	√	√		√		√			√	√	√	√						
Flooded soil with emergent grasses		√	√	√	√			√		√			√			√	√				√	
Marginal suspended and emergent grasses			√	√	√			√		√			√			√						
Mud with plant debris		√	√	√		√	√		√	√	√	√	√							√		
Washed plant debris with floating grasses			√										√									
Floating grasses			√					√		√						√						
Flooded soil		√	√		√			√		√											√	

Mud		√	√	√		√		√		√			√		√	√	√		√			√
Mud and plant debris with floating grasses		√	√	√	√				√				√		√	√			√			
Decaying plant debris		√	√	√	√			√		√			√	√		√						
Mud and decaying plant debris		√	√	√	√			√		√			√		√	√					√	
Soil and emergent plants with floating grasses		√	√	√	√			√	√		√		√									
Washed plant debris	√	√	√		√				√	√	√		√			√						

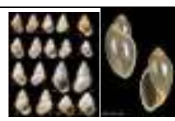
Appendix 4: Plot location with the general description

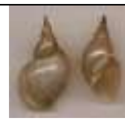
Latitude	Longitude	Elevation	Sites	Plot code	Plot description
239502	9795661	1313	Kageyo	KMP1	• Still water. highly turbid. used for rice field irrigation. traditional fishing and swimming. • The bank is made up of stony wall. no marginal vegetation. • Level of water increased during high precipitation • Catchments dominated by human settlements • No buffer zone.
238352	9796559	1308	Kageyo	KMP2	• Slow-flowing canal at the margin of rice field; shallow and turbid water used for rice and other crops irrigation. • Bank with emergent grasses including *Cyperus*. • Covered by grasses during high precipitation • Catchments dominated with cultivated fields • No buffer zone.
237560	9797801	1300	Kageyo	KMP3	• Canal with stagnant water at the margin of rice field; shallow and turbid water used for rice irrigation. • A few emergent grasses on the canal shore during low precipitation • Many grasses emerged during high precipitation • Catchment composed of cattle pasturage fields • No buffer zone.
237448	9800547	1300	Kageyo	KMP4	• Marginal rice irrigation canal. shallow and highly turbid and still water. • Emergent marginal weeds often cleared out for canalization activities. • Catchment with cultivated fields for a variety of crops. • No buffer zone
237894	9804023	1303	Gatindo	GMP1	• Flooding originating from Kageyo dam. shallow. low turbidity. • Level of water increased during high precipitation and flooded • Catchment with agricultural field for a variety of crops and some pastureland • Emergent vegetation dominated by *Caesalpinia decapetala* • No buffer zone
239169	9804638	1300	Gatindo	GMP2	• Shallow water. less turbid. flooding caused by Gatindo dam. • Level of water increased during high precipitation • Catchment consisting of pastureland for cattle. • No buffer zone.
239174	9806062	1299	Gatindo	GMP3	• Deep water. less turbid. pumped for uphill irrigation and cattle drinking. • Bank consisting of dam barrage constructed with soil. • Level of water increased and flooded during high precipitation • Catchments with cultivated fields and pastureland upward. • Crop residues around cows and sheep stayed there during the day for drinking water. grazing and resting • Generator and canals pumping water for cattle drinking and uphill irrigation • Soil cracks in low precipitation • No buffer zone

239088	9805535	1301	Gatindo	GMP4	• Flooding water originating from Gatindo dam with very low turbidity • Emergent vegetation • Canals transporting water for irrigation • Catchments consisting of cultivated land • No buffer zone.
239176	9806188	1299	Gatindo	GMP5	• Exit canal draining the Gatindo dam. open shallow and less turbid water • Canal constructed by cement during high precipitation • The canal flowing through marshland disturbed by cow drinking water and grazing with *Cyperus spp* around the canal. • People swimming and washing home materials • Often cut down for animal bed & fodder. • Catchments consisting of pastureland for cattle. • No buffer zone
234558	9814940	1294	Mucucu	MMP1	• Water highly turbid. shallow. stagnant. largely covered by *Azolla. Hydrocotyle. Enhyda* and *Ludvigia*. • Covered by a lot of grasses during high precipitation • Level of water increased during high precipitation • Water pumped for upland cattle drinking. Catchment of pastureland field • No buffer zone.
233311	9816235	1307	Mucucu	MMP2	• Occasional pools. highly turbid. shallow. stagnant. used for cow drinking. • Marginal vegetation consisting of emergent *Cyperus spp*. • Flooded during high precipitation • Catchment consisting of pastureland fields. No buffer zone.
232541	9817878	1289	Mucucu	MMP3 (left)	• Very deep. less turbid water. used for fishing activities and cow drinking. • Open bank. no vegetation during low precipitation • Covered by vegetation during high precipitation • Permanent generator and tubes allowing water in farms • Stones as fens against erosion within dam during high precipitation • Water expended to the nearest surfaces during high precipitation • Pastureland soil within dam because of flood • Catchment consisting of pastureland for cattle • No buffer zone.
32116	9817938	1285	Mucucu	MMP4 (right)	• Deep. less turbid water. Bank: open dike of the dam. • Flooded during high precipitation and water expended at the nearest surfaces. • Activities of canalization by MINAGRI increase the soil at the edge of the dam • Many Phytoplankton grown within dam during high precipitation • Traditional fishing activities at this side • Catchment consisting of pastureland fields. • No buffer zone

232043	9817830	1294	Mucucu	MMP5	• Patchy pool. shallow. highly turbid. fully covered by *Azolla. Pistia* and *Nymphea*. • Area disturbed by cow grazing activities. Catchment composed of pastureland field. • Many dungs from cattle which stay every day there for water drinking and grazing • Eutrophication. • Water jacinthe. • No buffer zone.

Appendix 5: Photos of sampled BMI

BMI family name	BMI photo
Aechnidae	
Ampullaridae	
Belostomatidae	
Bulinidae	
Chironomidae	
Coenagrionidae	
Conoesucidae	
Dytiscidae	
Hirudinidae	
Hydrophilidae	
Libellulidae	

Limnichidae	
Lymnaeidae	
Nepidae	
Physidae	
Planorbidae	 
Simuliidae	
Tateidae	
Thiaridae	
Tipulidae	
Mayflies	
Unionidae