IMPACT OF HABITAT MODERATION BY WEIR INSTALLATION ON INVERTEBRATE AND FISH COMMUNITIES IN RIVERS AWACH–SEME (KENYA) AND NAMBALE (UGANDA)

BY

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university or any other award.

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DEDICATION

This work is dedicated to my dear late parents, Mr. and Mrs. Kongo, who supported and encouraged me to pursue my education.
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I owe a great deal of thanks to all the people who have generously given me their time and energy during the two years of my studies. I am grateful to my supervisors Dr. Benson Mwangi and Dr. James Jumbe for guiding me. Dr. Benson Mwangi provided me with all the research equipment and financial support that I used for the work through funding by VicRes. I thank Mr. John Opiyo of KEMFRI for technical support and the Seme Awach and Bungokho communities for their cooperation. I thank Kenyatta University and Eldoret University for allowing me to use their laboratories.

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May the Lord bless you all.
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ACRONYMS AND ABBREVIATIONS

BOD: Biochemical Oxygen Demand
CPUE: Catch per Unit Effort
CBD: Convention on Biological Diversity
CPN: Catch per Net
CPOM: Coarse Particulate Organic Matter
EAC: East African Community
ESMF: Environmental and Social Management Framework
EU: European Union
FAO: Food and Agriculture Organization
FFG: Functional Feeding Groups
GDP: Gross Domestic Product
GPS: Global Positioning System
ILEC: International Lake Environment Committee
KARI: Kenya Agriculture Research Institute
KMFRI: Kenya Marine and Fisheries Research Institute
LKB: Lake Kyoga Basin
LLDA: Laguna Lake Development Authority
LVB: Lake Victoria Basin
LVBC: Lake Victoria Basin Commission
LVEMP: Lake Victoria Environment Management Program
LVFO: Lake Victoria Fisheries Organisation
TDS: Total Dissolved Solutes
EU: European Union
USAID: United States Agency for International Development
WHO: World Health Organisation
WKIEMP: Western Kenya Integrated Ecosystem Management Project
ABSTRACT

The Lake Victoria Basin (LVB) rivers and streams once rich in biodiversity have been undergoing degradation over the years resulting in decline in fish productivity. Studies have mainly focused on large rivers in Kenya and Uganda. Impacts of habitat alteration by weir installation as a river management tool are lacking. This study aimed at comparing the limnological responses of Rivers Awach Seme (Kenya) and Nambale (Uganda), after weir installation. Data was collected monthly for six months from November 2012 to April 2013 after weir installation in October 2012. River morphology, physical-chemical characteristics, riparian vegetation composition, organic matter, benthic invertebrates and fish community assemblages were assessed. The river morphology was studied by measuring stream width and depths. The physical-chemical characteristics were assessed by measuring stream velocity, water temperature, transparency, conductivity, pH, dissolved oxygen and total dissolved solutes (TDS). Fish and benthic invertebrate were caught using an electrofisher and Hess sampler respectively and their community structures were determined. Data was analysed using Statistical Package for Social Sciences (SPSS) version 16.0) where the probability value (P< 0.05) was used for the two tailed tests. Results showed that the rivers differed markedly in their morphology with River Nambale (Uganda) being heavily eroded while River Awach Seme (Kenya) was generally well protected. Physical-chemical characteristics of the two rivers did not differ significantly with pH averaging 7.55±0.10 for Nambale and 7.54±0.08 for River Awach Seme. Similarly, conductivity, dissolved oxygen and TDS did not differ significantly with means of 204±14.25 µScm⁻¹, 9.2± 0.46 mgl⁻¹ and 102±7.08 mgl⁻¹ respectively for River Nambale and 201±18.05 µScm⁻¹, 9.6±1.13 mgl⁻¹, and 100±7.89 mgl⁻¹ respectively for River Awach Seme. Riparian vegetation of the rivers consisted of similar species. More organic matter accumulated on the weir in River Nambale than at River Awach Seme with means of 965.1±64.39gm⁻² and 619.5±67.23 gm⁻² respectively. The lowest accumulation occurred in December 2012 while the highest in February 2013. Five orders of macroinvertebrate were sampled in River Awach Seme and they included Ephemeroptera, Trichoptera, Diptera, Coleoptera and Odonata. In addition to the five orders, order Megaloptera and class Hirudinae (Phylum Annelida) were observed in River Nambale. Fish species at the two rivers were similar. They included Barbus nyanzae Whitehead, Barbus kerstenii Peters, , Barbus jacksoni Gunther, Barbus albianalis Boulenger, Barbus cercops Whitehead, Clarias gariepinus Burchell Labeo victorianus Boulenger, and Gambusia affins Baird and Girard. In River Nambale, the fish community was dominated by Barbus nyanzae which constituted 40% of the total catch. Similarly, Barbus albianalis dominated the fish community of River Awach Seme constituting 46% of the total catch. Weirs impacted strongly on the river morphology and resulted in an increase in fish and macroinvertebrate abundance downstream. There is therefore need for them to be constructed as a river management tool. However, further long term surveys on invertebrate colonization succession, organic matter decomposition rates and additional niches created after weir installation are recommended to ascertain the impact of weir installation as a river management tool.
CHAPTER 1: INTRODUCTION

1.1 Background Information

Lake Victoria Basin (LVB) has numerous rivers and streams, most of them flowing into Lake Victoria. The rivers include Kagera, Nzoia, Mara, Sondu-Miriu, Nyando, Kuja, Katonga and Sio among others. They contribute about 18% of the water volume of Lake Victoria at any one time. River Nile, the only outlet, contributes about 24% of water leaving Lake Victoria at any one time. Lake Kyoga Basin (LKB) neighbours LVB and its principal in-flow is the Victoria Nile River. Other large effluents of Lake Kyoga include River Namatala, Mpologoma, Okere, Sezibwa, Omunya and Manafwa. Prior to the construction of the Owen Falls Dam in 1954, there was no effective barrier separating the flora and fauna in Lakes Victoria and Kyoga (LVBC, 2011).

Streams have been degraded by anthropogenic activities throughout the world. Such activities have included channelization, removal of riparian vegetation, agricultural and industrial pollution, hydrological alterations and bad land use practices (Reich et al., 2009). Such activities affect the distribution, survival and production of fish and other aquatic flora and fauna, cause the loss and degradation of critical habitats in addition to disrupting community structures (Van Zyll De Jong et al., 1997). Channelization reduces habitat for aquatic flora and fauna by increasing peak stream flow and reduction in benthic substrate heterogeneity. Sediments from overflow runoff and within channel erosion bury natural rock substrate resulting in reduced habitats (Litvan et al., 2008).

According to studies by Mbuligwe and Kaseva (2005), rivers and streams are very
important ecosystems for socio-economic development and sustainability of the environment since they provide a variety of valuable functions to the environment, national economies and the communities that depend on them. However, the systems are unable to provide basic functions to the rapidly growing population because they are threatened by pollution from various human activities.

Lake Victoria and Kyoga basins are prime areas of human settlement due to being immediate sources of water, food fish and hydro-power generation. Large human and livestock populations increase the rate of deforestation, erosion, sedimentation, siltation and nutrient loading into surrounding aquatic environments, which in turn, degrade the fish habitats (Bootsman and Hecky, 1993). Until the 1960s, LVB river fisheries were important due to migratory fishes like *Barbus altianalis* Boulenger, *Clarias gariepinus* Burchell and *Labeo victorianus* Boulenger. These fish were abundant before the Nile perch, *Lates niloticus* Linnaeus explosion after its introduction in the 1950’s and early 1960’s to improve the declining fisheries. Additionally, continued degradation of the riverine ecosystems since the early 1970s resulted in further decline of the riverine fish populations (Manyala and Ochumba, 1990). The decline in number of *Labeo* in Lake Victoria, Kenya waters has been attributed main to cultural practices which interfere with the breeding biology of the species (Cadwalladr, 1964). There was overfishing at the vicinity of river mouths, a practice which removed sexually mature fish before they spawned. This is due to the fact that *Labeo*, being anadromous, migrates upstream to spawn. Alongside overfishing was the extensive use of gillnets, a fishing gear which was more efficient than the weirs and barriers previously in operation.
The threats to riverine ecosystems in the LVB ecoregion include poor water quality, faunal and floral population reductions, highly eroded river banks and turbid waters. They are primarily human-induced on the land cover through removal of natural vegetation, siltation, pollution and over-exploitation of the resources such as the fisheries and climatic variability (LVB, 2011).

The Global reduction in biodiversity motivated nations to form the Convention on Biological Diversity (CBD, 1992) with the objective of conserving biodiversity. The riparian states of LVB and LKB are now implementing the measures for conservation and sustainable use of biodiversity as stipulated in Article 6 of CBD. Other key intervention areas include “Biodiversity identification and monitoring” (Article 7); In-situ conservation (article 8); Ex-situ conservation (article 9); Sustainable use (article 10); Research and training (article 12); Public education (article 13); and exchange of information (article 17). Studies on management challenges of fresh water fisheries in Africa (Ogutu-Ohwayo and Balirwa, 2006) revealed that sustainable management of the fishery resources of LVB is being undertaken through controlled fishing efforts. The European Union (EU) has provided support to generate information for managing Lake Victoria fisheries and this is assisting the Lake Victoria Fishery Organization (LVFO).

Vannote et al. (1980) formulated the hypothesis that from headwaters to downstream extent, the physical variables within a stream system present a continuous gradient of conditions including width, depth, velocity, flow volume, temperature, and entropy gain.
Biological organization in rivers conforms structurally and functionally to kinetic energy dissipation patterns of the physical system. Biotic communities rapidly adjust to any changes in the redistribution of use of kinetic energy by the physical system.

The model has been developed specifically in reference to natural, unperturbed stream ecosystems as they operate in the context of evolutionary and population time scales. However, the concept should accommodate many un-natural disturbances as well, particularly those which alter the relative degree of autotrophy: heterotrophy (e.g. nutrient enrichment, organic pollution, alteration of riparian vegetation through grazing, clear-cutting, etc.) or affect the quality and quantity of transport (e.g. impoundment, high sediment load).

These alterations can be thought of as reset mechanisms which cause the overall continuum response to be shifted toward the headwaters or seaward depending on the type of perturbation and its location on the river system. Weir installation is a way of habitat alteration.

In response to deteriorating conditions of streams, river regulation using weirs has been used in many streams in North America, Europe, Australia and elsewhere (Almeida et al., 2009). Weirs are structural features of the impoundment built across rivers for raising the level of rivers or streams in order to minimize fluctuation in the depth of the river upstream with changes in the flow rate. They are small overflow-type dams used to maintain the vertical profile of a stream or channel. Preliminary studies on riverine fisheries productivity and water quality enhancement through Weir and Riparian
Vegetation propagation technologies (Mwangi et al., 2012) in rivers Awach Seme and Kisiani, Kenya have revealed that fisheries productivity can be stimulated by this technology and there is need for further follow up studies on the effectiveness of the weirs in restoring stream health. Hydraulic structures such as weirs increase the amount of Dissolved Oxygen (DO) in a river system even though the water is in contact with the structure for only a short period of time (Ahmet and Tamer, 2000). Cokgor and Kucukali (2005) found that weirs can appreciably increase aeration efficiency by creating turbulent conditions. DO is used as an indicator of the quality of water used by humans or serving as a habitat for aquatic flora and fauna. Studies involving the impact of water barriers on freshwater invertebrates have been carried out in dams (Zhou et al., 2008), but weirs have received relatively little attention, especially in Africa, although such structures can remarkably improve stream health.

Weirs cause changes in stream morphology (canalization and dredging) and hydrology (flow regulation) and induce an alteration of habitats and changes in biotic and abiotic processes in streams (Sarriquet et al., 2007). Heterogeneity of microhabitats derived from flow regimes is important to diversity of benthic communities (Armitage, 2006; Almeida et al., 2009). River hydrology (flow) has a major influence on the composition, distribution and temporal variability of macrophyte communities (Humphries et al., 1996).

Weirs are widely used in stream management because of their effect of stimulating increase in density and diversity of macroinvertebrates and other benthic organisms
(Litvan et al., 2008). This improves the stream ecosystem health. In-stream hydraulic structures facilitate fine particles’ deposition and therefore improve aquatic invertebrate habitats (Zika and Peter, 2002; Negishi and Richardson, 2003; Roni et al., 2006;). Aquatic invertebrates are an important food source for fish and form part of the links in aquatic food chains. Weirs reduce flow rate in fast- moving currents and create pools. They also create resting and spawning areas for fish in addition to trapping gravel. This increases fish species richness, abundance and diversity.

In comparison with other ecosystems in LVB and LKB, river ecosystems are the least studied, and where studies have been carried out, this has been intermittent with no systematic trends. Most studies have focused on large rivers like Sondu-Miriu, Kuja, Nzoia, Yala and Nyando (Manyala and Ochumba, 1992; Ojwang’ et al., 2007). It has been indicated very well that studies on small rivers such as Awach Seme (Kenya) and Nambale (Uganda) are scanty. Mwangi et al. (2012), studying the situational analysis of benthic invertebrates and fish community structures in Rivers Kisiani and Awach Seme, Kenya, revealed that most of the fish species caught constituted the ichthyofauna community of Lake Victoria and therefore the rivers act as refugia to the lakes fisheries. For example, Barbus altianalis and Labeo victorianus, which disappeared from the lake, were abundant in the river’s ecosystems which may therefore be a source of recolonization. The study also revealed that the rivers may be an important source of fish if appropriate management interventions are instituted. The aim of this study was to compare the impact of weirs on benthic invertebrates and fish community structures in Rivers Awach Seme, Kenya and Nambale, Uganda, both of which are of similar size.
1.2 Statement of the Problem

There has been a decline in fish production in Lake Victoria and the neighbouring Lake Kyoga (Odada et al., 2004), and this is a challenge to food supply to the human population in Lake Victoria basin ecological region. A report by the Ministry of Agriculture, Livestock and Fisheries-Kenya (2013) revealed a decrease in fish production from 133801 tonnes (2011) to 118992 tonnes (2012). The neighbouring country-Uganda, also recorded a decline in fish production with a decrease in export to the EU from 14080 tonnes (2009) to 12375 tonnes (2010). Studies that have been carried out in the rivers of Lake Victoria ecological region have revealed that there is degradation yet there is increased demand for fish food for humans (LVBC, 2011). Knowledge on the limnology of small rivers like Awach Seme (Kenya) and Nambale (Uganda) is still scanty despite the fact that they face threats of human disturbance. Infact the effects of habitat alteration by introducing instream structures on the riverine biodiversity of such ecosystems are unknown yet its known that such structures may greatly improve the rivers’ water quality, invertebrate and fish diversity. Weirs modify local conditions and present conducive habitats for benthic macroinvertebrates. They create habitat complexity by increasing variability in stream depth, width, bottom substrate and current velocity. This study aimed at comparing the impacts of habitat alteration by installing low lying weirs on the benthic macro invertebrates and fish community structure in Rivers Awach Seme (Kenya) and Nambale (Uganda) which, though contrasting in their geographical location, have similar hydrological characteristics.
1.3 Objectives

1.3.1 General Objective
The overall objective is to carry out the analysis of benthic invertebrates and fish community assemblages of Rivers Awach Seme and Nambale in response to installation of weirs.

1.3.2 Specific Objectives
i. To assess the impacts of Weir installation on morphological characteristics of River Awach Seme in Kenya and River Nambale in Uganda.

ii. To assess the impacts of Weir installation on water quality conditions of the two rivers.

iii. To determine the response of benthic invertebrates and fish community assemblages to Weir installation among the rivers.

iv. To assess the benthic invertebrates and fish community assemblages between the upper and lower parts of the weirs in each of the two rivers.

1.4 Research Questions
i. Are there any differences on the impacts of Weir installation on the morphological characteristics of Rivers Awach Seme and Nambale?

ii. Does water quality differ between the two rivers after weir installation?

iii. Are there any differences in the response to Weir installation of benthic invertebrates and fish community assemblages among the two rivers?
iv. Do the benthic invertebrates and fish community assemblages differ between upstream and downstream of weirs in each of the two rivers?

1.5 Hypotheses

i. There is no significant difference on the impacts of weir installation on the morphological characteristics of Rivers Awach Seme and Nambale.

ii. There is no significant difference on the impacts of weir installation on water quality conditions of the two rivers.

iii. Responses of benthic invertebrates and fish community assemblages among the two rivers do not differ significantly.

iv. Benthic invertebrates and fish community assemblages do not differ significantly between the upper and lower parts of the weir in each of the two rivers.

1.6 Justification

The current study is a comparison of the benthic invertebrates and fish community structures of Rivers Awach Seme (Kenya) and Nambale (Uganda) in response to weir installation. Weirs can improve habitat conditions and cause high levels of macroinvertebrate density and diversity and this has a positive influence on the fish species diversity in the streams following increased energy transfer in the food webs. Improved macroinvertebrate and fish diversity will result in an increase in fish productivity thereby availing more protein and increased employment opportunities for the riparian human population of Lake Victoria basin ecological region.
CHAPTER 2: LITERATURE REVIEW

2.1 Stream Morphology

Studies by Sarriquet et al. (2007) revealed that weirs cause changes in stream morphology (canalization and dredging) and hydrology (flow rate) thereby, inducing an alteration of habitat and changes in biotic and abiotic processes in streams. The diversity of benthic communities is influenced by the heterogeneity of microhabitats derived from flow regimes (Almeida et al., 2009). Reduced flow changes the in-stream environment by decreasing flow velocity, depth, wetted width and taxonomic richness (James et al., 2008). According to Balcombe et al. (2007), depth is the most important parameter that influences invertebrate distribution and density. Benthic invertebrate communities in small streams may be altered by flow alterations and weirs.

2.2 Water Quality Conditions

The water quality conditions of a river are determined by the relative status of physico-chemical parameters which include temperature, pH, electrical conductivity, Dissolved Oxygen (DO), flow rate and transparency. When these conditions are optimum, the aquatic environment is conducive for floral and faunal survival (Sarkar et al., 2002). According to studies by Santos-Borja and Nepomuceno (2006), rapid migrations to urban centres and uncontrolled human settlement along river banks and lakeshore areas contribute to increased deposition of solid and liquid wastes into the aquatic habitats. Changes in environmental factors such as water quality and depth, water current, food
availability and substrate along a river influences the occurrence, abundance and distribution of the fish fauna (Bisht et al., 2009; Soyinka et al., 2010).

Melanie et al. (2011) studying the effects of weir on structural stream habitats and biological communities in Bavaria, Germany revealed that physicochemical habitat characteristics discriminated strongly between upstream and downstream of weirs installed in the study rivers. DO and temperature were higher upstream of weir than downstream whereas pH was higher downstream. Conductivity was least discriminative between upstream and downstream of weir.

Studies by Ogutu-Ohwayo and Balirwa (2006) on Lake Baringo and its catchment rivers revealed that sedimentation contributes to loss of fish habitat, fisheries and biodiversity. Out of the seven rivers which were flowing into the lake in 1970s, only one was still flowing into the lake in 2006. Sedimentation caused loss of many fish species such as Labeo victorianus and Oreochromis niloticus. Balirwa and Bugenyi (1980) found out that Webuye paper mill effluents deplete oxygen and are toxic to aquatic biota in River Nzoia, which was once a habitat of L. victorianus. Mumias sugar factory is also situated in River Nzoia basin. Its effluents not only alter the river composition, but also fish behaviour as well. In polluted rivers, aquatic organisms that are sensitive to oxygen stress and fluctuation in temperature, e.g. Ephemeroptera, Trichoptera and Plecoptera tend to be replaced by organisms that live in mud with low oxygen concentration such as the Chironomids and Annelida (Sarkar et al., 2002). A report by LVBC (2011) indicates that the physicochemical conditions in Rivers Yala, Sondu-Miriu, Nzoia and Kagera
have been changing but appear to have escalated from the mid-1970s due to industrialization, hydro-power generation, irrigation and urbanization impacts on natural riverine ecosystems.

Since the 1980s, water hyacinth, *Eichhornia crassipes* Mart has been a challenge to the LVB fisheries (Ogutu-Ohwayo and Balirwa, 2006). The weed invaded Lake Naivasha in 1988 and Lake Victoria in 1990 from where it spread to the rivers in the lake catchment ecosystems (Harley, 1991; Twongo, 1996). The weed covers shallow sheltered bays, which are suitable fish breeding and nursery grounds. It has negative effects on DO and water transparency and this reduces the fish breeding and nursery grounds (Twongo and Balirwa, 1995).

Weirs have an effect on water quality because they cause physical conditions which remarkably differ from the conditions of free-flowing streams although the chemical and thermal differences only occur locally (Pohlon *et al.*, 2007). Nutrient concentrations in streams vary through time and this is due to a number of factors including temperature, evaporation and discharge (McNamara *et al.*, 2008). Anthropogenic aquatic ecosystem inputs include manure, synthetic fertilizers, detergents and sewage (Heathwaite *et al.*, 1996; Shields Jr *et al.*, 2009). The loading of nutrients has adverse effects on water quality changes (Heathwaite *et al.*, 1996). Studies by Roni *et al.* (2006) revealed physical habitat improvement following boulder weir inclusion in streams though with no effect on water chemistry and nutrient levels.
2.3 Riparian Vegetation

Riparian vegetation is the flora on land that adjoins and directly influences or is influenced by a body of water. Studies by Alam et al. (2004) in the lower Fitzroy River, Australia, suggested river rehabilitation by restoration of riparian vegetation zones along the waterways to reduce nutrient and sediment inputs to improve and maintain water quality. In addition to this, riparian vegetation is a source of energy and organic matter for aquatic ecosystems (Decamps, 1984; Naima and Decamps, 1997). Riparian vegetation further controls and recycles allochthonous inputs from the upland riverine drainage basins and the rivers themselves (Brinson et al., 1984; Schlosser and Karr, 1981; Peterjohn and Correll, 1984).

Studies by Holly et al. (2013) linking forest harvest and landscape factors to benthic macroinvertebrate communities in the interior of British Columbia revealed that assessing the importance of anthropogenic changes such as forest harvest on ecological condition in the context of natural variation across the landscape is essential for natural resource management because it allows managers to account for differences on how ecosystems respond to disturbances. Removal of riparian vegetation can lead to increased light and fine sediment, and higher maximum temperatures, which in turn have been linked to reduced survival and disrupted life cycles in benthic invertebrates (Sweeney, 1993; Quinn et al., 1994).

Studies by Doskey et al. (2010) revealed that excessive land use through removal of riparian vegetation along river banks led to increased run off resulting into changes in
river hydrology and influx of silt, nutrients and other dissolved substances. Riparian vegetation influences stream water chemistry through diverse processes including direct chemical uptake and indirect influences such as supply of organic matter to soils and channels, modification of water movements, and stabilization of soil. Studies by Nakiyemba et al. (2010) on Iguluibi catchment (Uganda) revealed that removal of riparian vegetation tends to accelerate surface erosion.

2.4 Benthic Macro Invertebrates

Benthic macro-invertebrates are important in the food chains of aquatic environments because they play a role in processing and cycling of nutrients in addition to being a major food source for fish and other aquatic animals (Ansari et al., 2003). Fluctuations in physico-chemical parameters can cause long- or short-term shifts in invertebrate community richness, abundance and species composition. An increase in nutrient, organic matter or food source for instance, has been shown to result in low diversity of macro-invertebrates, with an increase in abundance of stress tolerant species (Sarkar et al., 2002).

Mengzhen et al. (2014), studying the effects of pollution on macroinvertebrates and water quality bio-assessment, revealed that organic pollutants affect macroinvertebrates taxa richness and composition of functional feeding groups. Taxa richness decreases dramatically with total nitrogen increasing. scrapers, shredders, predators and collector-filterers decrease or even disappear, while collector-gatherers become extremely
dominant. Furthermore, increase in total nitrogen, results in extremely non-uniform distribution of the functional feeding groups in circumstances of high organic pollution.

Instream structures (dams and weirs) modify local hydraulic conditions there by presenting suitable habitat for benthic invertebrates (Gore et al., 1998). Boulder weirs are known to increase habitat surface area which is in turn readily colonised by benthic invertebrates (Litvan et al., 2008). Fjellheim and Raddum (1996) reported high ecological importance of weir basins in rivers due to their reduction in discharge. Delayed downstream transport of organic matter and trapping of detritus and drifting invertebrates avails more energy to the detritus feeders in the river but may have negative effects towards downstream productivity.

Studies by Melanie et al. (2011) revealed that weir installation caused a difference in macronvertebrate abundance and species richness between upstream and downstream of weir. The pronounced weir effects detected in this study suggested a strong alteration in community structure, productivity and the diversity of stream ecosystems. These alterations were an interruption of the natural gradient of physical habitat conditions and the biotic responses from the headwater to the mouth of river systems (Ward and Stanford, 1983), as originally described in the river continuum concept by Vannote et al. (1980). Reduced flow changes the in-stream environment by decreasing flow velocity, depth, wetted width and taxonomic richness (James et al., 2008). Flow velocity has a significant impact on the density of riverine invertebrates. Streams that are subjected to
extreme low flow and increased sedimentation have low macroinvertebrate diversity (Wood and Armitage, 1999).

Increased flow results into higher current velocities which may cause a change to the coarse substratum (Growns and Growns, 2001). According to Balcombe et al. (2007), stream depth influences invertebrate distribution and density. The health of a river ecosystem is determined by equilibrium among all physical, chemical and biological factors (Fleituch, 2003). These factors operate in conjunction with each other resulting in improved river health.

Mulanda et al. (2010), studying macro-invertebrates’ community structure in Rivers Kipkaren and Sosiani, Kenya, found significant differences between the mean abundance and taxa richness of macro-invertebrates between the rivers. They suggested that the differences may be accounted for by changes in anthropogenic activities along the rivers. According to Mathaei et al. (2000), the distribution of benthic macro-invertebrates in streams is dynamic and strongly influenced by anthropogenic impacts which cause changes in physico-chemical parameters. Besides being important links in aquatic food chains, benthic invertebrate communities are increasingly studied (Tumiwesigye et al., 2000) and used as ecological disturbance indicators due to their sensitivity to environmental changes and ease of sampling.
2.5 Riverine Fish Species Diversity

Riverine fish species diversity refers to all the fish species present in a defined river and their relative abundance. According to Benade (1993), anthropogenic activities in the Orange River system (South Africa) resulted in a threat to fish species survival and this caused a reduction in species diversity. The river’s fish fauna occurrence, abundance and distribution was also affected by changes in environmental factors such as water quality and depth, water current, food availability and the substratum along the river (Bisht et al., 2009; Soyinka et al., 2010).

Studies by Zeni and Casatti (2013) on the influence of habitat homogenization on the trophic structure of fish fauna in the tropical streams (Rivers Sao Jose dos Dourados and Turvo-Grande in south east Brazil) revealed that riparian canopy had a modulating role in the trophic structure of stream fishes. It influences the allochthonous resources supply (i.e. fruits and insects), habitat heterogeneity of channel (by providing, i.e. branches, trees trunks and leaves), and light availability. Riverside grasses provide microhabitats for macroinvertebrates and this influences the abundance and biomass of aquatic insectivores. This consequently plays a key role in trophic homogenization. Removal of riparian forests and spread of riverside grasses may lead to future functional homogenization. Further, weirs can alter water temperature, discharge and sediment deposition (Tonkin et al., 2009). Temperature affects the seasonal distribution and density of invertebrates (Balcombe et al., 2007) and this greatly affects the riverine fishes (Jackson and Marmulla, 2000).
Melanie et al. (2011) studying the effects of weirs on structural stream habitats and biological communities in Bavaria, Germany found that fish species richness and CPUE were higher downstream than upstream of weir. Diversity was also higher and more even downstream. In addition to the differences in abundance, species richness, diversity and community composition between upstream and downstream of weir, there was an indication of weir effects on fish community structure and the availability of ecological niches. The “habitat heterogeneity hypothesis” (Conner and McCoy, 1979), states that an increase in the number of habitats and, at a different scale, an increase in their structural complexity leads to an increased species diversity. A large number of (micro) habitats practically mean a large number of niches exploitable by different species (Tews et al., 2004).

According to a report by LVBC (2011), LVB ecosystem had an extremely high diversity of fish species prior to 1960’s. The rivers had a number of riverine fish species which included L. victorianus, B. altianalis, Schilbe intermedius Ruppell, Synodontis spp and Brycinus spp.

These fish were abundant before L. niloticus explosion after introduction in the 1950’s and early 1960’s to improve the declining fisheries. The fish also reduced in stock size as a result of overfishing at the river mouths when the fish migrated to riverine environments for breeding. Studies by Ogutu and Balirwa (2006) on management challenges of freshwater fisheries in Africa revealed that degradation of fisheries and other resources normally starts with human overpopulation, which results in
overexploitation of resources. This situation can then be followed by introduction of new species to improve catches (Ogutu-Ohwayo and Hecky, 1991).
CHAPTER 3: MATERIALS AND METHODS

3.1 Study Sites

3.1.1 Location

Rivers, Awach Seme (Kenya) and Nambale (Uganda) are fourth and third order streams respectively. They are located within LVB Eco-region in the East Africa Community (EAC). The Eco-region comprises mainly Lake Victoria with associated satellite lakes and the neighbouring basin of Lakes Kyoga, Edward, George and Kivu. Within the eco-region are a number of rivers and streams which drain into the lakes. These include Rivers Nzoia, Yala, Sondu Miriu, Sio, Nyando, Mogusi, Migori, Kisiani and Awach Seme in Kenya and Rivers Nile, Kagera, Ruizi, Malaba, Mpologoma, Kafu, Manafwa, Namatala and Nambale in Uganda. River Awach Seme is situated in Kisumu county (Kenya) at latitude 00°04’S and longitude 34°38’E. Its source is the Maseno Highlands and it drains into Lake Victoria (Figure. 3.1).
Figure 3.1: Location of the study site along River Awach Seme.
River Nambale is located in Bungokho sub-county in Eastern Uganda. It arises from Mbale forest on Nkokonjeru Hills in Mbale District. The river is situated at latitude 01°02’N and longitude 34°10’E and is a tributary of River Namatala which drains into Lake Kyoga (Figure 3.2).

Figure 3.2: Location of the study site along River Nambale.
3.1.2 Climate and Geomorphology
Awach Seme basin receives a bimodal rainfall pattern with the short season from October to December and the long one from March to July (Kenya meteorological report, 2012/2013). The annual rainfall fluctuates between 258.0 to 816.0mm. The mean annual temperature is 23°C with a range of 2°C. The upper catchment of River Awach Seme experiences heavy and fluctuating rainfall which occasionally causes floods in the middle and lower reaches.

The river substratum of River Awach Seme consisted of boulders, stones and sand (Appendix). The riparian vegetation was composed of Markhamia platycalyx Sprague, Psidium guajava L., Solanum inca-num L. Lantana camara, Tithonia diversifolia Hemsl, Ficus spp, Mimosa spp and Acacia spp among others. The riparian vegetation protects most of the river bank. However, there were sections which had been cleared by farmers.

Like Awach Seme, River Nambale basin receives a bimodal type of rainfall. The long rain season is during the months of March to June and the short one in the months of September to November. The river substratum of River Nambale consisted mainly of sand and silt (Appendix). Riparian vegetation was composed of T. diversifolia, S. inca-num, Ficus spp, L. camara and M. platycalyx among others.

3.1.3 Anthropogenic Activities
Anthropogenic activities at the sampling site of River Awach Seme included; farming, livestock keeping, sand harvesting, mining and fishing. The crops cultivated included;
kales, maize, beans, cowpeas and ground nuts. Human activities at River Nambale sampling sites included subsistence farming, animal husbandry, agro-forestry and fishing. Maize, sweet potatoes, cassava, millet, sorghum, bananas, sugar cane, kales, cabbage, eggplant, irish potatoes, coffee, beans, ground nut and cow peas were among the crops cultivated.

3.1.4 Selection of Study Sites
River Awach Seme study area covered the section of the river approximately 100m on the left of Kolenyo Bridge on Kisumu- Bondo road, 58km from Kisumu town (Figure 3.1). The river is one of the small rivers flowing into Lake Victoria in Kenya and is polluted in some sections by the riparian human population through livestock keeping, car washing and farming activities. Its altitude and relatively small size allowed easy sampling and road accessibility. This made it a good choice for sampling during the study. The study area had two sampling sites that included a riffle on the lower side and a pool on the upper side of the weir (Plate 3.1). A gabion weir was constructed at the GPS location of latitude 00°06’51”S and longitude 34°38’28”E at altitude 1321m ASL.
Plate 3.1: Gabion boulder weir at River Awach Seme (Kenya).

In River Nambale, the study area covered the section of the river approximately 100m on the left of Bungokho Bridge, along Tororo-Mbale road, 5km from Mbale town (Figure 3.1). Like River Awach Seme, Nambale River is small. It is a tributary of River Namatala which flows into Lake Kyoga in Uganda. It is polluted as a result of anthropogenic activities. Its small size allows for easy sampling and it is easily accessed by road. This is the reason why it was a good choice for sampling during the study. The study area had two sampling sites, each of which included a riffle on the lower side and pool on the upper side of the weir (Plate 3.2). The weir was constructed at the GPS
location of latitude 01°00′45″N and longitude 34°10′18″E at altitude 1247m ASL. The two rivers were selected because of their similar hydrological characteristics. Both rivers experience short rains from September to December and long rains from March to July.

Plate 3.2: Gabion boulder weir at River Nambale (Uganda).
3.2 Research and Sampling design

3.2.1 Research Design
In this study, a situational assessment of benthic invertebrates and fish community structures in response to weir installation was carried out in Rivers Awach Seme (Kenya) and Nambale (Uganda). Weirs were installed at the study sites in the two rivers in October 2012. Following this, sampling was carried out for a period of six months from November 2012 to April 2013. This sampling period covered both the rainy and dry seasons of Rivers Awach Seme and Nambale basins.

3.2.2 Sampling Design
Systematic sampling design was applied where six samples of benthic macroinvertebrates were taken- three from the lower and three from the upper side of weir at intervals of 5m from the weir (Figure 3.3). Two samples of fish were taken- one representing 100m downstream and the other 100m upstream of weir (Figure 3.4). Stream depth, width and water quality conditions were measured at intervals of 5m from the weir- upstream and downstream. Organic matter accumulation on the weirs installed in two rivers was assessed monthly during the study period. Stream velocity was measured upstream and downstream of weir. Riparian vegetation was examined along a 200m long transect on either side of river bank upstream of weir.
3.3 Assessment of morphological characteristics

The river depth and width at full bank were measured using a meter rule and tape measure respectively (Plate 3.3). This was done at intervals of 5m from the weir - both upstream and downstream. 8 samples of river depth were taken: 4 from upstream and 4 from downstream of the weir to the nearest cm. Average depth was calculated for the 4 readings for upstream and downstream of weir. 8 samples of river width were measured to the nearest metre: 4 upstream and 4 downstream of weir. The average for each of the 4 samples was calculated.
Discharge was measured by a subsurface float (Gordon et al., 1992). The time taken for a float object to traverse a distance of 10 metres upstream and downstream respectively was recorded using a stop watch. The float was introduced upstream to attain the speed of water prior to passing the first mark. An average speed was calculated from three runs. The surface velocity was calculated as (\( V_{\text{surface}} \)). \( V_{\text{surface}} = \frac{L}{t}; \)

Where L= distance travelled in metres

\( t= \) time travelled in seconds

\( V_{\text{surface}} \) was in m/s.
Plate 3.3: Measurement of stream morphology of the sampling sites along River Nambale, Uganda.

3.4 Assessment of Water Quality Changes

Water quality changes were assessed using a multi-probe meter (HI 991300 pH/EC/TDS Temp) through in situ measurements of water temperature, hydrogen-ion concentration (pH), conductivity and total dissolved solutes (TDS). Air temperature was measured using a portable thermometer. A portable DO meter (HI 9142) was used to measure the concentration of dissolved oxygen. The values for the physico-chemical parameters from the two samples from the study area were averaged to obtain a value to represent the
water quality measure for the study area. Measurement of the physico-chemical parameters was done once per month at each study site.

3.5 Assessment of Riparian Vegetation
Riparian vegetation species composition was examined along a transect 200m long on either side of the river bank. Where possible, identification of the plant species was done in situ. Samples of the plant material would also be preserved for identification at the National Museum of Kenya. Assessment of riparian vegetation was done once a month at the sampling sites.

3.6 Assessment of Organic Matter Accumulation on Weir
Accumulation of organic matter on the weirs was assessed by collecting three samples of vegetation trapped on the surface of the weir within Hess Sampler’s area (0.0299m²). In the laboratory, the sampled wet vegetation was dried in an oven at 105°C until constant weight (x). This was to eliminate water. The dry sample was then subjected to a temperature over 105°C until constant weight (y). The difference between x and y, i.e. (x-y) was calculated to give the amount of organic matter accumulation on the weir within Hess Sampler’s area (gm⁻²). The values for accumulated organic from the three samples from the study area were averaged to obtain a value to represent the accumulated organic matter measure for the weir.
3.7 Benthic Macro Invertebrates sampling and analysis

Benthic Macro Invertebrates were sampled from two sites which consisted of a riffle on the lower side and a pool on the upper side of each of the weirs in Rivers Awach Seme and Nambale. This was carried out once a month. The samples were collected using a Hess sampler with an area of 0.0299m$^2$ and mesh size of 100µm (Plate 3.4). The sampler was carefully inserted into the substrate to a depth of 8-12cm to enable collection of many benthic macro invertebrates (Euliss et al., 1992). Sampling was done by walking upstream in the river bed to avoid collection of induced drift organisms. The sampler’s enclosed area was vigorously stirred up for 2 minutes. The enclosed small cobbles and organic matter trapped in the sampler cylinder were washed off by hand. Benthic macro invertebrates dislodged in the sampling process were passed through the conical net (100 µm) into a detachable collecting tube sealed at the rear with a fine mesh (100 µm). The animals were backwashed out of the tube using a wash bottle into sample bottles and immediately fixed in 70% alcohol on-site for further sorting. Six samples of benthic macro-invertebrates- three on the lower and three on the upper side of the weir were collected during each sampling session. The samples were transported to the laboratory for identification and enumeration.

Benthic macro-invertebrates were processed by washing through 100µm sieves prior to sorting them using a dissecting microscope. Specimens were identified as far as possible and preserved. The sorted orders were separately preserved in 70% alcohol and later on further sorted to family and genera where possible. Identification was done using pertinent literature (Gerber and Gabriel, 2002; Cummins et al., 2004; Tomanova et al.,...
2005) in Kenyatta University (Zoological Sciences laboratory) where the material was stored.

Macro-invertebrate density (D) was estimated as;

\[ D = \frac{N}{0.0299m^2}, \]

Where: \( D \) = number of individuals per m\(^2\) of streambed area

\( N \) = total number of individuals

0.0299m\(^2\) = Hess-sampled area.

Shannon-Wiener diversity index-\( H' \) was applied in the assessment of differences in macro invertebrate diversity and distribution between sites.

Diversity was determined using Shannon index;

\[ H' = -\sum ((ni/N) \log_e (ni/N)), \] (Shannon and Weaver, 1949).

Where \( H' \) = Shannon index of diversity

\( ni \) = number of individuals for each Taxon

\( N \) = total number of individual

\( \log_e \) = natural log.
3.8 Fish sampling and community analysis

Fish Species Composition, Abundance and Diversity were established after collection of samples from Rivers Awach Seme and Nambale. Two sampling sites were selected, one representing the upper side of the weir and the other representing the lower side of the weir. Each site was 100m long though with variations in width and depth. Fishing was carried out once a month. Fish samples were captured by means of a portable electric fisher (SAMUS-725G) - (Plate 3.5). The electric fisher instantly immobilized the fish but caused minimum disturbance to the habitat. During fishing, stop nets were used to
demarcate the sampling site to prevent fish migration during sampling sessions. Sampling was done from downstream to upstream and the downstream drifting fish were collected by means of a seine net. On every sampling day, electro fishing was carried out for a time period of 90min per site subject to water depth, terrain and catches. In this study, fishing effort was measured as the length of fishing time per day, i.e. 3 hours per day. Catch per unit effort (CPUE) was defined as grams of fish per km per hour (g/km/h).

Fish samples were counted and identified on site using external morphological features with the assistance of an expert from Kenya Marine and Fisheries Research Institute (KMFRI) and manuals of Boulenger (1909-1915); Greenwood (1966); Lothar et al. (2003); Okaronon et al. (1997) and Eccles (1992). Unidentified fish specimens were preserved in 70% alcohol for further identification at the National Museum of Kenya. All fish samples captured were measured for total and standard lengths to the nearest 0.1mm and weighed to the nearest 0.1g. Immediately after measurement, live fish were released back into the rivers.

The fish species abundance was expressed as a percentage of the identified member species relative to the total number of fish observed. Fish species diversity was determined by use of Shannon-Weiner’s Diversity Index (H’) (Shannon, 1964). Species evenness (E_H) was determined in order to find out whether the individual species were evenly distributed among the total species present (Dash, 2001; Batter, 1976). For each
sampling session, the fish catch per unit effort (g/km/hr) was calculated to determine the fisheries productivity status for each of the rivers (Irwan et al., 2014).

Shannon-Wiener Diversity Index and Species evenness were calculated as follows;

\[ H' = -\sum pi \log_e Pi, \quad E = \frac{H^1}{\text{Ins}} \]

Where: \( H \) = Index of diversity
\[ \sum pi = \text{Sum of percentage values of species} \]
\( E \) = Species evenness
\( H^1 \) = Species diversity of site i
\( \text{Ins} \) = Natural logarithm of species number
Plate 3.5: A portable electrofisher (SAMUS-725G) used in fish sampling at Rivers Awach Seme, Kenya and Nambale, Uganda.

### 3.9 Data Analysis

The data was analysed using Statistical Package for Social Sciences (SPSS version 16.0). The probability value of $P<0.05$ was used for all the two tailed tests to show statistical significance of mean values for all the parameters that were analysed. Fish species abundance was expressed as a percentage of the identified member species relative to the total number of fish observed. Fish and benthic invertebrates’ Shanon-Weiner’s Diversity Index ($H'$) was calculated to determine the taxa diversity (Shannon, 1964). Batters evenness ($E_H$) was calculated to determine taxa distribution among the species.
present (Batter, 1976). Upstream and downstream of weir benthic invertebrate taxa abundance were compared using t-test (Harrison and Antony, 2004). Pearson’s correlation was applied to explore the congruence between fish catch and benthic invertebrate’s colonization of weir. Water quality parameters, stream depths and stream widths were compared downstream and upstream of weir using Mann-Whitney U test (Zivorad, 2010). Kruskal-wallis test was used to determine if there were any significant differences in water quality, stream depths and widths in the rivers during the study period (Vishwa et al., 2013).
CHAPTER 4: RESULTS

4.1 Impact of Weir installation on River Morphology

4.1.1 Stream Depth

Stream depths of Rivers Awach Seme and Nambale did not differ significantly during the sampling period (Kruskal-wallis test, H=2.956, d.f.=3, P>0.05). Mean stream depth of River Awach Seme was however greater than that of River Nambale upstream of the weirs throughout the study period (Table 4.1). The stream depth at River Awach Seme, upstream of weir varied from 20cm in February 2013 to 111cm in November 2012, with a mean of 37.83± 4.47cm (Table 4.1). Downstream of weir, stream depth varied from 20cm to 100cm, reaching a high of 100cm in the month of November 2012 and a low of 20cm in February 2013. Downstream of weir, mean depth was 47.48±9.49cm. The two mean depths did not differ significantly (Mann-Whitney U test, U=18.000, P>0.05).

Stream depth of River Nambale varied from 11cm to 66cm upstream of weir. The depth reached a high of 66cm in December 2012 and a low of 11cm in January 2013. Upstream of weir, mean depth was 31.08± 6.11cm (Table 4.1). In contrast, the stream depth downstream of weir varied greatly from 5cm in January 2013 to high of 88cm, in December 2012. Downstream of weir, mean depth was 47.83± 9.96cm. Upstream and downstream mean depths did not vary significantly (Mann-Whitney U test, U=18.000, P>0.05).
Table 4.1: Change in stream depth (cm) in Rivers Awach Seme (Kenya) and Nambale (Uganda) upstream and downstream of the weirs during the study period (Nov. 2012 to Apr. 2013), n =4.

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<th>River Awach Seme</th>
<th>River Nambale</th>
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<tr>
<td></td>
<td>UW</td>
<td>DW</td>
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<td></td>
<td>Mean</td>
<td>SE</td>
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<td>0m</td>
<td>40.50</td>
<td>10.23</td>
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<td></td>
<td>7.28</td>
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<tr>
<td>5m</td>
<td>31.00</td>
<td>5.95</td>
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<tr>
<td></td>
<td>2.74</td>
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</tr>
<tr>
<td>10m</td>
<td>49.33</td>
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<td>3.22</td>
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<tr>
<td>15m</td>
<td>30.50</td>
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<td>6.51</td>
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<tr>
<td>Mean</td>
<td>37.83</td>
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<tr>
<td>SE</td>
<td>4.47</td>
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</table>
| UW = Upstream of weir.  
DW= Downstream of weir.

4.1.2 Stream Width
Stream widths for Rivers Awach Seme and Nambale differed significantly during the study period (Kruskal-wallis test, H=9.956, d.f.=3, P< 0.05). Mean stream widths at both upstream and downstream of River Awach Seme were greater than for River Nambale with a range of 3.5m to 9m as compared to a range of 1.8m to 7.5m at River Nambale. Mean stream width upstream of weir was 7.14± 0.31m at River Awach Seme (Table 4.2). Downstream of weir, the stream width also varied greatly from 3.5 to 10.4m during
the study period. Downstream of weir, the mean stream width was higher measuring 7.20 ± 0.63m, although the two mean stream widths did not differ significantly (Mann-Whitney U test, U=30, P > 0.05). At River Nambale, stream width varied from 2 to 5m upstream of weir, with a mean of 3.55 ± 0.15m. Downstream of weir, stream width varied from 1.8m to 7.5m, with a mean of 4.12 ± 0.11m (Table 4.2). Like River Awach Seme, the mean widths at River Nambale did not differ significantly between upstream and downstream of weir (Mann-Whitney U test, U=30, P > 0.05).

Table 4.2: Change in stream width (m) at full bank in Rivers Awach Seme (Kenya) and Nambale (Uganda) at the weirs during the study period (Nov 2012 to Apr 2013), n = 4.

<table>
<thead>
<tr>
<th>River Awach Seme</th>
<th>River Nambale</th>
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<td>UW</td>
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<td>Mean</td>
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<td>0m</td>
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<td>5m</td>
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<tr>
<td>10m</td>
<td>7.16</td>
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<td>15m</td>
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<td>Mean</td>
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UW = Upstream of weir.
DW = Downstream of weir.

4.1.3 Stream Surface Velocity
The upstream and downstream mean velocities of River Awach Seme were both higher than those of River Nambale during the study period. During November 2012 and April
2013, stream velocity at River Awach Seme averaged 0.24±0.05m/s compared to a mean of 0.26±0.16m/s at River Nambale, upstream of weir (Figure 4.1). Downstream of weir, stream velocity at River Awach Seme averaged 0.87±0.11m/s while at River Nambale, the mean was 0.35±0.20m/s ((Figure 4.1). During this period, the velocity was generally higher in both rivers probably due to increased water volume available during the rainy season.

Stream velocity at River Awach Seme, upstream of weir, varied greatly from 0.13 to 0.36m/s with a mean of 0.23±0.03m/s as compared to a variation of 0.61 to 0.98m/s downstream of weir, with a mean of 0.73±0.06m/s (Figure 4.1). At River Nambale, stream velocity upstream of weir varied greatly from 0.09 to 0.42m/s with a mean of 0.25±0.06m/s (Figure 4.1), while downstream of weir, velocity varied from 0.09 to 0.54m/s with a mean of 0.21±0.07m/s (Figure 4.1).
Figure 4.1: Temporal variation in stream velocity at River Awach Seme and Nambale from November 2012 to April 2013.

Stream velocity generally increased downstream of weir in both rivers due to the impounded structures (weirs). However, during the months of February and March 2013, velocity in River Nambale was greater upstream of weir than downstream velocity and this was as a result of sand harvesting downstream of weir (Plate 4.1). This created a pool at the immediate downstream of weir thereby reducing the velocity.
Plate 4.1: River bank degradation due to sand harvesting at River Nambale (Uganda)

4.2 Impact of Weir installation on Water Quality

4.2.1 Water Temperature

Water temperature in Rivers Awach Seme and Nambale did not differ significantly (Kruskal-wallis test, H=0.561, d.f.=3, \( P > 0.05 \)). In River Awach Seme, the temperature ranged from 23.3 to 24.6°C upstream of weir with a mean of 24.1±0.19°C (Table 4.4). Water temperature varied from 23.6 to 25.2°C downstream of weir, with a mean of 24.4±0.20°C. Mean water temperature did not differ significantly between upstream and downstream of weir (Mann-Whitney U test, U=13.0000, \( P > 0.05 \)), although there was a slight water temperature elevation downstream of weir. The highest temperature was recorded in April 2013 while the lowest was in December 2012 (Figure 4.2).
Figure 4.2: Comparison of temporal variation in water temperature (°C) between Rivers Awach Seme and Nambale during the study period.

At River Nambale, water temperature ranged from 22.4 to 26.2°C upstream of weir with a mean of 24.4 ± 0.59°C as compared to a variation of 22.7 to 26.5°C and a mean of 24.6 ± 0.60°C downstream of weir (Table 4.4). The two means were significantly different (Mann-Whitney U test, U=14.000, P > 0.05). The highest temperature was recorded in December 2012 while the lowest was observed in March 2013 (Figure 4.2).

4.2.2 Water Transparency
Water transparency did not differ significantly between Rivers Awach Seme and Nambale (Kruskal-wallis test, H=6.684, d.f.=3, P > 0.05). In River Awach Seme, water transparency ranged between 4.3 to 17.3cm upstream of weir, with a mean of 11.0 ± 2.1cm (Table 4.4). Variation of water transparency was slightly greater downstream of weir ranging from 4.3 to 23cm with a mean of 11.5 ± 2.8cm although the
two means did not vary significantly (Mann-Whitney U test, U=16.500, P > 0.05). The highest water transparency was recorded in April 2013 while the lowest was observed in March 2013 (Figure 4.3). At River Nambale, water transparency ranged from 7.5 to 26.5cm upstream of weir, with a mean of $18.3 \pm 2.5$cm (Table 4.4). Downstream of weir however, water transparency varied from 9.5 to 16.5cm, with a mean of $14.0 \pm 1.0$cm, although the two means did not differ significantly (Mann-Whitney U test, U=6.000, P > 0.05). The highest water transparency at River Nambale was in December 2012 while the lowest was observed in April 2013 (Figure 4.3).

![Figure 4.3: Comparison of temporal variation in water transparency (cm) between Rivers Awach Seme and Nambale during the study period.](image)

4.2.3 Water pH

The mean water pH at River Awach Seme did not differ significantly between upstream and downstream of weir (Mann-Whitney U test, U=17.000, P > 0.05). Upstream of weir,
pH ranged from 7.4 to 7.7 with a mean of 7.53 ± 0.05 as compared to a range of 7.4 to 7.8, with a mean of 7.54 ± 0.10 downstream of weir (Table 4.4). The highest water pH was recorded in November 2012 while the least was in April 2013 (Figure 4.5).

**Table 4.3: Water quality impacts at Rivers Awach Seme (Kenya) and Nambale (Uganda) during the sampling period.**

<table>
<thead>
<tr>
<th></th>
<th>River Awach Seme</th>
<th></th>
<th>River Nambale</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before weir</td>
<td>After weir</td>
<td>Before weir</td>
<td>After weir</td>
</tr>
<tr>
<td></td>
<td>Upstream N=6</td>
<td>Downstream N=6</td>
<td>Upstream N=6</td>
<td>Downstream N=6</td>
</tr>
<tr>
<td>H₂O temp (°C)</td>
<td>27</td>
<td>21.4±0.19</td>
<td>24.9</td>
<td>24.4±0.59</td>
</tr>
<tr>
<td>Transparency(cm)</td>
<td>11.0±2.09</td>
<td>11.5±2.80</td>
<td>7.59</td>
<td>7.55±0.10</td>
</tr>
<tr>
<td>pH</td>
<td>7.85</td>
<td>7.53±0.05</td>
<td>7.59</td>
<td>7.55±0.10</td>
</tr>
<tr>
<td>Conductivity (µScm⁻¹)</td>
<td>232</td>
<td>206±20.1</td>
<td>229</td>
<td>205±14.5</td>
</tr>
<tr>
<td>TDS (mg⁻¹)</td>
<td>117</td>
<td>101±8.27</td>
<td>113</td>
<td>103±7.05</td>
</tr>
<tr>
<td>DO (mg⁻¹)</td>
<td>-</td>
<td>9.2±1.12</td>
<td>-</td>
<td>9.0 ±0.41</td>
</tr>
</tbody>
</table>

Similarly, pH at River Nambale did not differ significantly between upstream and downstream of weir (Mann-Whitney U test, U=16.000, P > 0.05), with a range of 7.5 to 8.0, (mean of 7.55± 0.10) upstream of weir and 7.3 to 8.0 (mean of 7.55± 0.10) downstream of weir (Table 4.5). The mean water pH at Rivers Awach Seme and Nambale did not differ significantly (Kruskal-wallis test, H=0.153, d.f.=3, P > 0.05). The highest pH was during the month of December 2012 as compared to the lowest which was recorded in March 2013 (Figure 4.4).
Figure 4.4: Comparison of temporal variation in water pH between Rivers Awach Seme and Nambale during the study period.

4.2.4 Water Conductivity

Water conductivity varied from 166 to 300µScm\(^{-1}\) (mean of 206± 20.1µScm\(^{-1}\)) upstream of weir at River Awach Seme (Table 4.4). Downstream of weir, water conductivity decreased, ranging from 156 to 265µScm\(^{-1}\) with a mean of 197± 16.0 µScm\(^{-1}\). The decrease however was not significant (Mann-Whitney U test, U=13.500, \(P > 0.05\)). Conductivity was highest in March 2013 and lowest during the month of November 2012 (Figure 4.5).
Figure 4.5: Comparison of temporal variation in Water Conductivity (µScm\(^{-1}\)) between Rivers Awach Seme and Nambale during the study period.

At River Nambale, water conductivity varied from 151 to 246µScm\(^{-1}\) (mean 205± 14.5µScm\(^{-1}\)) upstream of weir as compared to a range of 152 to 244µScm\(^{-1}\) (mean 202±14.0 µScm\(^{-1}\)) downstream of weir (Table 4.4). The decline in conductivity was however not significant (Mann-Whitney U test, U=16.000, P > 0.05). The highest conductivity was in February 2013 while the lowest in March 2013 (Figure 4.5). Water conductivity in Rivers Awach Seme and Nambale did not differ significantly (Kruskal-wallis test, H=0.375, d.f.=3, P > 0.05).

**4.2.5 Total Dissolved Solutes**

Total Dissolved Solutes (TDS) varied from 83 to 138mgL\(^{-1}\) upstream of weir at River Awach Seme, with a mean of 101± 8.27mgL\(^{-1}\) while downstream of weir, it ranged from 82 to 132mgL\(^{-1}\) with a mean of 99± 7.50 mgL\(^{-1}\) (Table 4.4). The decrease was however not
significant (Mann-Whitney U test, U=13.500, P > 0.05). The highest TDS value was recorded in March 2013 while the lowest in November 2012 (Figure 4.6).

Figure 4.6: Comparison of temporal variation in Total Dissolved Solutes (mgl⁻¹) between Rivers Awach Seme and Nambale during the study period.

In River Nambale, TDS ranged from 78 to 117mgl⁻¹ (mean 103± 7.05mgl⁻¹) upstream of weir as compared to a range of 76 to 123mgl⁻¹ (mean 101± 7.10mgl⁻¹) downstream of weir (Table 4.4). Despite the small decline in TDS, difference in means was not significant (Mann-Whitney U test, U=15.00, P > 0.05). The highest TDS value was recorded in February 2013 while the lowest in March the same year (Figure 4.6). The mean TDS between Rivers Awach Seme and Nambale did not differ significantly (Kruskal-wallis test, H=0.394, d.f.=3, P > 0.05).
4.2.6 Dissolved Oxygen

Dissolved oxygen at River Awach Seme ranged from 5.5 to 12.4mg/l (mean 9.2±1.12mg/l) upstream of weir, as compared to a range of 5.6 to 13.8mg/l (mean 10.0±1.13mg/l) downstream of weir (Table 4.4). The two means did not vary significantly (Mann-Whitney U test, U=14.000, P > 0.05). The highest DO value was recorded in March 2013 while the lowest in April the same year (Figure 4.7).

At River Nambale, DO ranged between 7.9 and 10.5mg/l upstream of weir, with a mean of 9.0±0.41mg/l (Table 4.4). Downstream of weir, DO varied from 8.1 to 11.4mg/l with a mean of 9.3±0.50mg/l. There was no significant difference between the two means (Mann-Whitney U test, U=15.000, P > 0.05). The highest DO value was observed in January 2013 while the lowest was recorded in November 2012 (Figure 4.7).
The mean DO levels between Rivers Awach Seme and Nambale differ significantly (Kruskal-wallis test, H=0.540, d.f.=3, P > 0.05).

4.3 Response of benthic invertebrates community assemblages to weir installation

A total of 3028 benthic macroinvertebrates were collected from the sampling sites of River Awach Seme (Table 4.6). The macroinvertebrate community structure was mainly dominated by 5 insect orders. The orders included, Ephemeroptera, Trichoptera (Plate 4.2), Diptera, Coleoptera (Plate 4.3) and Odonata (Table 4.5). Simulidae (order Diptera) was the most dominant with a mean 36.4± 11.7 downstream of weir. The mean abundances of families Caenidae, Chironomidae, Simulidae and Hydropsychidae did not differ significantly between upstream and downstream of weir (t-test, p>0.05).
Table 4.4: Invertebrate taxa composition and abundance (Nos./m²) obtained from Rivers Awach Seme and Nambale during the sampling period.

<table>
<thead>
<tr>
<th>Taxa</th>
<th>River Awach Seme</th>
<th></th>
<th></th>
<th>River Nambale</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U W</td>
<td>D W</td>
<td>U W</td>
<td>D W</td>
<td>U W</td>
<td>D W</td>
</tr>
<tr>
<td><strong>Ephemeroptera</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caenidae</td>
<td>10.8</td>
<td>3.7</td>
<td>12.3</td>
<td>2.7</td>
<td>27.6</td>
<td>8.4</td>
</tr>
<tr>
<td>Heptageniidae</td>
<td>2.5</td>
<td>0.8</td>
<td>2.9</td>
<td>1.1</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Baetidae</td>
<td>4.2</td>
<td>1.3</td>
<td>5.1</td>
<td>1.5</td>
<td>3.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Leptophlebiidae</td>
<td>0.5</td>
<td>0.2</td>
<td>0.3</td>
<td>0.2</td>
<td>1.1</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Diptera</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chironomidae</td>
<td>19.1</td>
<td>7.7</td>
<td>25.7</td>
<td>6.4</td>
<td>40.0</td>
<td>11.3</td>
</tr>
<tr>
<td>Ceratopogonidae</td>
<td>0.4</td>
<td>0.2</td>
<td>1.4</td>
<td>0.4</td>
<td>3.1</td>
<td>0.7</td>
</tr>
<tr>
<td>Dixidae</td>
<td>0.5</td>
<td>0.3</td>
<td>0.6</td>
<td>0.4</td>
<td>1.3</td>
<td>0.6</td>
</tr>
<tr>
<td>Simulidae</td>
<td>13.7</td>
<td>5.5</td>
<td>36.4</td>
<td>11.7</td>
<td>19.7</td>
<td>9.0</td>
</tr>
<tr>
<td>Tipulidae</td>
<td>0.4</td>
<td>0.3</td>
<td>0.4</td>
<td>0.2</td>
<td>1.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Athericidae</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Odonata</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Libellulidae</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Trichoptera</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydropsychidae</td>
<td>9.2</td>
<td>3.3</td>
<td>20.1</td>
<td>7.4</td>
<td>1.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Hydropilidae</td>
<td>0.1</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td><strong>Coleoptera</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elmidae</td>
<td>0.8</td>
<td>0.3</td>
<td>1.3</td>
<td>0.4</td>
<td>1.6</td>
<td>0.7</td>
</tr>
<tr>
<td>Gyrinidae</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Megaloptera</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corydiidae</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Annelida</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hirudiniae</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1.7</td>
<td>1.4</td>
</tr>
<tr>
<td>N</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
</tbody>
</table>


Plate 4.2: Trichoptera; Hydropsychidae larva

Plate 4.3: Coleoptera: Gyrinidae larva
At River Nambale, a total of 4307 benthic macroinvertebrates were collected during the study period (Table 4.6). The community structure consisted of six orders of macroinvertebrate, five of which also occurred in River Awach Seme (Table 4.5). Order Megaloptera and members of class Hirudinae (Phylum Annelida) were also present. Family Chironomidae was the most abundant with means of 40.0± 11.3 and 56.8± 19.4 upstream and downstream of weir respectively. Downstream of weir, mean abundances for Caenidae, Chironomidae, Simulidae and Hydropsychidae were higher although the upstream and downstream taxa mean abundance did not differ significantly (t-test, P>0.05). The macroinvertebrate abundance between River Awach Seme and Nambale did not differ significantly (t = -1.079; d.f = 61; P>0.05). Similarly, in both rivers, there was no significant difference between the upstream and downstream macroinvertebrate abundance (t-test, P>0.05).

**Table 4.5: Benthic invertebrate’s community characteristics of River Awach Seme (Kenya) and Nambale (Uganda) in the Lake Victoria Basin Eco-region.**

<table>
<thead>
<tr>
<th>Community Index</th>
<th>River Awach Seme</th>
<th>River Nambale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of individuals</td>
<td>3028</td>
<td>4307</td>
</tr>
<tr>
<td>Taxa diversity (H)</td>
<td>4.792</td>
<td>2.382</td>
</tr>
<tr>
<td>Taxa richness (S)</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>Taxa evenness (E_H)</td>
<td>0.342</td>
<td>0.140</td>
</tr>
</tbody>
</table>

River Awach Seme had a taxa richness and diversity of 15 and 4.792 respectively (Table 4.7). On the contrary, a higher taxa richness of 17 was recorded in River Nambale. Despite this, River Nambale had a lower taxa diversity of 2.382 (Table 4.6).
4.4 Colonization of organic matter by Benthic Macroinvertebrates

There was high macroinvertebrate colonization of the organic matter that accumulated on the weir in River Awach Seme (Table 4.7). On the lower side of weir, macroinvertebrate colonization consisted of mainly filtering collectors which included Simulidae and Hydropsychidae and gathering collectors consisting of Chironomidae, Ceratopogonidae and Elmidae. In contrast, a small number of macro-invertebrate colonized the upper side of the weir. These consisted of shredders which included Chironomidae (Table 4.5).

Table 4.6: Colonization of organic matter by benthic- macro invertebrates on the lower and upper side of weir at River Awach Seme (Kenya), n =6.

<table>
<thead>
<tr>
<th>Sampling Date</th>
<th>Lower side of weir</th>
<th>Upper side of weir</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean number of indiv/m²</td>
</tr>
<tr>
<td>09/11/2012</td>
<td>3</td>
<td>5516.4 ± 3483.3</td>
</tr>
<tr>
<td>08/12/2012</td>
<td>3</td>
<td>5187.8 ± 2454.5</td>
</tr>
<tr>
<td>16/01/2013</td>
<td>3</td>
<td>4377.9 ± 2226.2</td>
</tr>
<tr>
<td>13/02/2013</td>
<td>3</td>
<td>2981.2 ± 2422.0</td>
</tr>
<tr>
<td>20/03/2013</td>
<td>3</td>
<td>1032.9 ± 613.4</td>
</tr>
<tr>
<td>26/04/2013</td>
<td>3</td>
<td>3474.2 ± 1851.7</td>
</tr>
</tbody>
</table>

In River Nambale, filtering and gathering collectors colonized organic matter on the lower side of weir. These included Simulidae, Hydropsychidae, Chironomidae,
Ceratopogonidae and Elmidae (Table 4.5). The upper side of weir was colonized by shredders which included Chironomidae and Tipulidae.

Colonization of the organic matter on the weirs by benthic macroinvertebrates was higher on the lower side than the upper side of the weir in both rivers, though River Nambale experienced a higher macroinvertebrate colonization of organic matter on the upper side of the weir during the month of February 2013 (Table 4.8).

<table>
<thead>
<tr>
<th>Sampling Date</th>
<th>Lower side of weir</th>
<th>Upper side of weir</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/11/2012</td>
<td>7030.5±4941.9</td>
<td>5633.8±2390.8</td>
</tr>
<tr>
<td>9/12/2012</td>
<td>5586.9±2916.1</td>
<td>4917.8 ±2064.8</td>
</tr>
<tr>
<td>18/01/2013</td>
<td>7523.5±3651.6</td>
<td>3626.8±1871.6</td>
</tr>
<tr>
<td>15/02/2013</td>
<td>868.5±514.8</td>
<td>2934.3±1555.5</td>
</tr>
<tr>
<td>22/03/2013</td>
<td>4882.6±2841.8</td>
<td>2887.3±2602.9</td>
</tr>
<tr>
<td>28/04/2013</td>
<td>2640.8±1012.2</td>
<td>2018.8±1755.0</td>
</tr>
</tbody>
</table>

4.5. Response of Fish Species Community to weir installation

The fish species in River Awach Seme consisted of seven species, dominated by *Barbus altianalis* Boulenger, (Plate 4.5), (Table 4.9). The other species sampled at the river included *Barbus nyanzae* Whitehead (Plate 4.4), *Barbus kerstenii* Peters, *Barbus jacksoni* Gunther, 1889 (Plate 4.6), *Clarias gariepinus* Burchell (plate 4.7), *Labeo victorianus* Boulenger and *Gambusa affinis* Baird and Girard (Table 4.9). Of these
species, *Barbus altianalis* constituted 46% of the total catch (Table 4.9) followed by *Barbus nyanzae* and *Clarias gariepinus* constituting 18% and 13.2% respectively.

Table 4.8: Comparison of the total count and relative abundance of fish species caught in Rivers Awach Seme (Kenya) and Nambale (Uganda).

<table>
<thead>
<tr>
<th>Species</th>
<th>River Awach Seme</th>
<th>River Nambale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ni</td>
<td>%</td>
</tr>
<tr>
<td><em>Barbus nyanzae</em></td>
<td>35</td>
<td>18.4</td>
</tr>
<tr>
<td><em>Barbus kerstenii</em></td>
<td>17</td>
<td>8.9</td>
</tr>
<tr>
<td><em>Labeo victorianus</em></td>
<td>3</td>
<td>1.6</td>
</tr>
<tr>
<td><em>Barbus jacksonii</em></td>
<td>22</td>
<td>11.6</td>
</tr>
<tr>
<td><em>Barbus cercops</em></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><em>Barbus altianalis</em></td>
<td>88</td>
<td>46.3</td>
</tr>
<tr>
<td><em>Clarias gariepinus</em></td>
<td>25</td>
<td>13.2</td>
</tr>
<tr>
<td><em>Gambusa affinis</em></td>
<td>1</td>
<td>0.003</td>
</tr>
</tbody>
</table>

ni= Total count.
Plate 4.4: *Barbus nyanzae* (Adel/ Kisinja)

Plate 4.5: *Barbus altianalis* (Adel/ Kisinja)
Similarly, the fish community of River Nambale consisted of seven species. All the fish species found in River Awach Seme were present except *Labeo victorianus* Boulenger.
Barbus cercops Whitehead, was the least represented constituting less than 1% of the total fish catch. Barbus nyanzae dominated constituting 40% of the total fish catch followed by Barbus kerstenii, Barbus jacksoni and Barbus altianalis at 23.2%, 13.4% and 13.4% total fish catch representation respectively. Despite both rivers having seven fish species, the abundance, species diversity and evenness was higher in River Nambale (Table 4.10).

Table 4.9: Fish species community characteristics in Rivers Awach Seme (Kenya) and Nambale (Uganda), n = 5.

<table>
<thead>
<tr>
<th>Community Index</th>
<th>River Awach Seme</th>
<th>River Nambale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total catch</td>
<td>191</td>
<td>368</td>
</tr>
<tr>
<td>Species diversity (H)</td>
<td>2.15</td>
<td>2.19</td>
</tr>
<tr>
<td>Species richness (S)</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Species evenness</td>
<td>0.307</td>
<td>0.313</td>
</tr>
</tbody>
</table>

A comparison of fish total catch between upstream and downstream of weir in both Rivers Awach Seme and Nambale revealed that more fish were captured downstream of weir (Table 4.11). In River Awach Seme, species diversity upstream and downstream of weir was the same, i.e. 1.94 (Table 4.11). In River Nambale, species diversity was higher upstream of weir. Species richness was higher downstream of weir in both Rivers Awach Seme and Nambale. On the contrary, species evenness was higher upstream of weir in the two rivers (Table 4.11). There was a positive correlation (Pearson correlation coefficient = 0.586) between the total fish catch and benthic macroinvertebrate colonization upstream and downstream of weir in both rivers.
Table 4.10: Comparison of fish community structure upstream and downstream of weir in Rivers Awach Seme (Kenya) and Nambale (Uganda), n =5.

<table>
<thead>
<tr>
<th>Community Index</th>
<th>River Awach Seme</th>
<th>River Nambale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UW</td>
<td>DW</td>
</tr>
<tr>
<td>Total catch</td>
<td>50</td>
<td>141</td>
</tr>
<tr>
<td>Species diversity (H)</td>
<td>1.94</td>
<td>1.94</td>
</tr>
<tr>
<td>Species richness (S)</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Species evenness (E_{H})</td>
<td>0.388</td>
<td>0.323</td>
</tr>
</tbody>
</table>

UW- Upstream of weir.

DW- Downstream of weir.

4.6 Fish Catch per Unit Effort

The fish catch per unit effort (productivity status) was higher in River Awach Seme despite River Nambale having higher total catch, species diversity and evenness. In both rivers, the upstream catch per unit effort was greater than the downstream catch per unit effort (CPUE) during the sampling period (Table 4.12). The highest fish CPUE was recorded in January 2013 averaging 23.65 g/km/hr and 15.35 g/km/hr in Rivers Awach Seme and Nambale respectively. In River Awach Seme the least CPUE was during March 2013 whereas in River Nambale, it was recorded in December 2012.

In River Awach Seme, fish catch per unit effort (CPUE) ranged from 5.9 to 39.0 (mean 21.62± 6.62) upstream of weir while downstream of weir, the range was between 1.2 and 11.6 (mean 5.66± 1.88) (Table 4.12). Upstream of weir, CPUE in River Nambale ranged from 0.2 to 14.6 with a mean of 8.12 ± 2.30 (Table 4.12). CPUE varied greatly between 0.8 and 21.8 downstream of weir with a mean of 7.02± 3.84.
Table 4.11: Fish catch per unit effort (g/km/hr) downstream and upstream of weir at Rivers Awach Seme (Kenya and Nambale (Uganda) per sampling session using the electro-fisher, n =5.

<table>
<thead>
<tr>
<th>Catch per fishing effort (g/km/hr)</th>
<th>River Awach Seme</th>
<th>River Nambale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UW</td>
<td>DW</td>
</tr>
<tr>
<td>December 2012</td>
<td>5.9</td>
<td>11.6</td>
</tr>
<tr>
<td>January 2013</td>
<td>39.0</td>
<td>8.3</td>
</tr>
<tr>
<td>February 2013</td>
<td>35.6</td>
<td>1.2</td>
</tr>
<tr>
<td>March 2013</td>
<td>11.5</td>
<td>3.1</td>
</tr>
<tr>
<td>April 2013</td>
<td>16.1</td>
<td>4.1</td>
</tr>
<tr>
<td>Mean</td>
<td>21.62</td>
<td>5.66</td>
</tr>
<tr>
<td>SE</td>
<td>6.62</td>
<td>1.88</td>
</tr>
</tbody>
</table>

UW- Upstream of weir.

DW- Downstream of weir.

4.7 Riparian Vegetation Species Composition

The riparian vegetation of Rivers Awach Seme (Kenya) and Nambale (Uganda) consisted of similar species (Table 4.3), albeit for the fact that the banks of River Nambale were more degraded than those of River Awach Seme (Plate 4.1). Awach Seme river bank riparian vegetation was dominated by Phragmites australis (Plate 4.8), while in River Nambale, riparian vegetation was dominated by Tithornia diversifolia. (Plate 4.9).
Plate 4.8: Dominant *Phragmites australis* at River Awach Seme (Kenya)
Plate 4.9: Dominant *Tithornia diversifolia* at River Nambale (Uganda)
Table 4.12: Riparian vegetation species composition on the banks of river Seme Awach and Nambale

<table>
<thead>
<tr>
<th>Species (Uganda)</th>
<th>River Awach Seme (Kenya)</th>
<th>River Nambale</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Markhamia platycalyx</em></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>Psidium guajava</em></td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>Solanum incanum</em></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>Tithornia diversifolia</em></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>Ficus spp</em></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>Mimosa spp</em></td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>Acacia spp</em></td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>Phragmites australis</em></td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>Eucalyptus spp</em></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>Pinus spp</em></td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>Cypress spp</em></td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>Dryopteris marginalis</em></td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>Pennicetum spp</em></td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>Musa spp</em></td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>Racinus communis</em></td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>Lantana camara</em></td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

+ means present.

- means absent.
4.8 Organic Matter Accumulation

Organic matter accumulation showed similar seasonal variation at both Rivers Awach Seme and Nambale, with organic matter accumulation steadily increasing from December 2012 to March 2013 (Figure 4.8). More organic matter accumulated at River Nambale than at River Awach Seme during the study period. In River Awach Seme, monthly organic matter accumulation on the weir varied from 329.3 to 738 g/m² with a mean of $619.5 \pm 67.23$ g/m² dry weight.

![Organic Matter Accumulation](image)

Figure 4.8: Organic matter accumulation (g/m²) in Rivers Awach Seme and Nambale during the study period.

Organic matter accumulation on the weir in River Nambale ranged between 572.3 and 965.1 g/m² with a mean of $965.1 \pm 64.39$ g/m². More organic matter accumulated during the dry months of January and February in both rivers due to decreased flow rates.
CHAPTER 5: DISCUSSION

5.1 Impact of weir installation on river morphology

Stream depths of Rivers Awach Seme and Nambale did not differ significantly during the sampling period. Upstream of weir, the stream depth of River Awach Seme was greater than that of Nambale throughout the sampling period because of anthropogenic activities of mining and sand harvesting in River Awach Seme upstream of weir. This is in agreement with findings by studies by Bootsman and Hecky (1993) who linked high human settlement along rivers to the degradation of river ecosystem health.

Rivers Awach Seme and Nambale stream widths were significantly different during the study period. In River Awach Seme, both upstream and downstream mean widths were greater than those recorded for River Nambale. This can be attributed to the higher stream velocity recorded during the study period. The stream velocity of River Awach Seme was higher and caused more erosion on the river bank thereby increasing the river width. This was further alleviated by the riparian human activities of clearing the riparian vegetation for cultivation. This is in agreement with findings by Bootsman and Hecky (1993) who linked high human settlement along rivers to the degradation of river ecosystem health.

Stream depths and widths were higher in rivers Awach Seme and Nambale during November and December 2012 respectively. This was as a result of increase in the stream water volume due to increased rainfall. Awach Seme basin experiences its short rain season from October to November. Similarly, short rain season in River Nambale
basin occurs during the months of September to November. These results are in line by findings by Jowett (2003) who stated that the degree of flow variability depends on rainfall variability, and, changes in water level during rainy season could lead to fluctuating water depths.

The Weirs impacted strongly on the morphology and hydrology of both Rivers Awach Seme and Nambale. They altered the stream depths, widths and velocity. This is in agreement with findings by Sarriquet et al. (2007). Weirs have strong impacts on the river morphological characteristics.

5.2 Impact of weir installation on water quality

At both Rivers Awach Seme and Nambale, water temperature did not differ significantly between downstream and upstream of weir although there was a slight increase downstream. This is in agreement with findings by Pohlon et al. (2007) whose investigations on the physic- chemical characteristics of River Ilm in Germany revealed that weirs do not affect the water temperature in the river column although they create distinct physical conditions. Studies by Zhou et al. (2008) revealed that modified river hydrology has an impact on water temperature. He found that rivers tend to be more dynamic in their temperature following diurnal solar cycle whereby water temperature is lowest in the morning and highest in the late afternoon.
At River Nambale, the remarkable decrease in water transparency downstream of weir may be linked to high levels of human activities around the sampling site. In contrast, at River Awach Seme, downstream of weir, water transparency did not decrease so much due to reduced human activities in the vicinity of the sampling site. This is in agreement with findings of Bootsman and Hecky (1993) who established that large human and livestock populations increase the rate of deforestation, erosion, sedimentation, siltation and nutrient loading into surrounding aquatic environments, which in turn degrade the faunal habitats.

In both Rivers Awach Seme and Nambale, there was a slight increase in DO downstream of weir due to water splashing. This is in agreement by studies by Ahmet and Tamer (2009) who discovered that weirs have strong impacts on the river water quality characteristics. They increase the amount of DO in a river system even though the water is in contact with the structure for only a short period of time. The slight increase in DO downstream of weir in both rivers was also partly related to fast stream flow rate on the bottom substrate which created turbulence. This is in agreement with findings by Cokgor and Kucukali (2005), who found that weirs can increase aeration efficiency by creating turbulence conditions. Dissolved oxygen is available for insect larvae and fish fauna with gills for gaseous exchange. At River Nambale, increase in DO downstream of weir was a very minimal. These was due to the bottom substrate which is composed of sand and silt which do not create much turbulent conditions like the boulders and stones in River Awach Seme.
The weirs did not remarkably affect conductivity in Rivers Awach Seme and Nambale. Similar results have shown that changes in conductivity after stream flow change is negligible (Pohlon et al., 2007). At both rivers, large fluctuations of conductivity were observed and this can happen after periods of rainfall (Grand River Conservation Authority, Cambridge, 2009).

At both Rivers Awach Seme and Nambale, the decrease in water pH downstream of weir was not remarkable. Almeida et al. (2009), studying D’Ouro and Santo Antonio Rivers, Brazil, found that weirs did not affect pH levels. Although they modify the physical habitat, weirs appear to have very little effect on chemical water characteristics. The slight changes in pH could be due to hydrological effects during the rainy seasons.

Total Dissolved Solutes (TDS) did not markedly decrease downstream of weir at both Rivers Awach Seme and Nambale. During the rains, TDS was higher in both rivers probably as a result of increased surface runoff from the surrounding agricultural farms. This is in agreement with findings by Adedokun et al. (2008), in Ibadan Metropolis in Nigeria, who stated that runoff water contributes to increase in TDS in rivers.

5.3 Response of benthic invertebrates community assemblages to weir installation

The higher benthic macro-invertebrate taxa richness and total number caught in River Nambale may be linked to the amount of organic matter accumulation on the weir. This
was due to high riparian vegetation cover on the river banks (personal observation). This is in agreement with findings by Conners and Naiman (1984) who found out that aquatic ecosystems rely on organic matter inputs from riparian zone and catchment for much of the energy needed to drive the stream food webs.

River Awach Seme had a higher taxa diversity and evenness of benthic macro-invertebrates because of its hydrology and morphology. It had stones, boulders and sand forming its substratum. The river had pools and riffles. The riffles caused turbulent flow, resulting in increased DO concentration, which supported higher densities of benthic invertebrates.

The weirs were colonized by a wide variety of benthic macro-invertebrates in both the rivers. Most of the macro-invertebrate functional feeding groups colonized the organic matter on the weirs and this was due to high CPOM that was trapped by the boulders and wire mesh used in weir construction. The weirs form very stable biotomes for fresh water communities (Mackay and Easburn, 1990). In both rivers, downstream of weir had higher benthic macro-invertebrate abundance due to the high DO concentration downstream.

There was a positive correlation between the total fish catch and benthic macro-invertebrate colonization upstream and downstream of weir in both rivers. This is because benthic macro-invertebrates are food for fish and therefore in increase in the macro-invertebrate population would result in an increase in the fish population. This is
in agreement with findings by Zeni and Casatti (2013), who found out that riverside grasses provide microhabitats for macro-invertebrates and this influences the abundance and biomass of aquatic insectivores.

5.4 Response of Fish Species Community to weir installation

The lower fish catch in River Awach Seme in comparison to River Nambale was linked to the higher anthropogenic activities in and around the river causing disturbance. The activities included livestock watering, sand harvesting, gold mining, farming and cloth washing. The overall species diversity in a previous study (Mwangi et al., 2012) was higher. This is an indicator of continued anthropogenic activities in stream degradation and therefore the need for implementation of the policies already in place for river protection. Both Rivers Awach Seme and Nambale had a higher species evenness indicating that the fish were more or less equally distributed among the present species although this was slightly higher in River Nambale. Both river ecosystems are therefore good habitats for a diverse fish species composition.

The higher fish species diversity in River Nambale may have been as a result of high riparian vegetation cover on the river banks (personal observation) and this is in agreement with findings by Dosskey et al., (2010) who found out that riparian vegetation influences supply of organic matter to the river channels. Organic matter is food for benthic invertebrates which in turn form links in riverine food webs.
Rivers Awach Seme and Nambale had higher fish species diversity and this may be due to their hydrological and morphological characteristics, which significantly promoted habitat heterogeneity (Kadye and Marshal, 2006). River Awach Seme was characterized by substratum consisting of boulders, stones and sand. This caused shallow pools and riffles. On the other hand, River Nambale substratum mainly consisted of sand and silt. The rivers consisted of alternating pools and riffles. The pool-riffle periodicity may be important in cycling of nutrients along a stream (Goldman and Horne, 1983). Riffles tend to support higher densities of benthic invertebrates and are therefore important food processing areas for fish.

In both Rivers Awach Seme and Nambale, *Clarias gariepinus* were captured in pools, both upstream and downstream of weir. River Awach Seme stream velocity was relatively higher and most of the *Clarias gariepinus* were caught in the pool immediately upstream of weir. This is in agreement by findings of Mwangi et al. (2012) who found out that *Clarias gariepinus* mostly inhabited stagnant water in river Awach Seme. Most of the fish were captured within the weirs’ adjacent environments- both upstream and downstream, (20m above and below). The weirs caused habitat heterogeneity by creating pools upstream and riffles downstream. The weirs were also colonized by benthic macro-invertebrates after trapping organic matter. The higher fish CPUE in January 2013 may be linked to more accumulation of organic matter on the weirs which in turn caused high colonization of the weirs by benthic macro-invertebrates. This was during the dry season. Rivers Awach Seme and Nambale experience their dry seasons during January and February.
5.5 Riparian Vegetation Species Composition

The riparian vegetation of both Rivers Awach Seme (Kenya) and Nambale (Uganda) consisted of *Markhamia platycalyx*, *Solanum incanum*, *Tithornia diversifolia*, *Ficus spp*, *Eucalyptus spp*, and *Lantana camara* although the banks of River Nambale were more degraded. This was due to activities of the riparian subsistence farmers who clear riparian vegetation for cultivation of crops. This is in agreement with findings by Doskey *et al.* (2010) who revealed that excessive land use through removal of riparian vegetation along river banks led to increased run off resulting in changes in river hydrology and influx of silt, nutrients and other dissolved substances.

5.6 Organic Matter Accumulation on Weir

Rivers Awach Seme and Nambale experienced organic matter accumulation on the weirs. The weirs delayed downstream transport of organic matter and trapped the downstream drifting invertebrates thereby availing more energy to the fish. This is in agreement with studies by Fjellheim and Raddun (1996). The rivers experienced the highest organic matter accumulation on the weirs in February 2013. This was probably due to low rainfall, which resulted in low stream water volume and therefore low stream velocity. During the rainy seasons, relatively little organic matter accumulated on the weirs in Rivers Awach Seme and Nambale.
CHAPTER 6: CONCLUSIONS, RECOMMENDATIONS AND AREAS FOR FURTHER RESEARCH

6.1 CONCLUSIONS

In this study, the effect of weirs on morphological characteristics and water quality conditions of rivers Awach Seme and Nambale was investigated. Benthic invertebrate and fish community assemblages were also studied. These were the conclusions arrived at:

(i) The Weirs impacted strongly on the morphology and hydrology of both Rivers Awach Seme and Nambale. They altered the stream depths, widths and velocity.

(ii) Weirs did not have a significant effect on water quality although there was a slight decrease for TDS and conductivity downstream. In both rivers, DO increased downstream.

(iii) Weirs resulted in accumulation of organic matter composed of leaves, twigs and fruits which provided large surface area for invertebrate colonisation.

(iv) Invertebrate abundance increased from upstream to downstream of weir surface, dominated mainly by Diptera (Chironomidae and Simulidae).

(v) Similar to the invertebrate distribution trends, fish increased in abundance downstream of weir as compared to upstream of weir in both rivers indicating that weirs have the potential of increasing fish abundance in rivers.
6.2 RECOMMENDATIONS

The following recommendations were drawn from the findings of this study.

(i) Since Weirs impacted strongly on the morphology and hydrology of both Rivers Awach Seme and Nambale, there is need to construct them and protect the natural ones from destruction by anthropogenic activities.

(ii) Weirs caused a slight decrease in TDS and conductivity downstream of weir in both rivers. There is therefore need for them to be constructed to improve water quality conditions.

(iii) Weir placement resulted in an increase in the abundance of invertebrates and fish downstream in both the rivers. They should therefore be included in rivers.

6.3 AREAS FOR FURTHER RESEARCH

(i) Further studies on colonization of succession of macro-invertebrates in the habitat created by the weir.

(ii) Further studies on decomposition rates of organic matter trapped by the weir.

(iii) Studies on additional niches created after weir installation.
REFERENCES


APPENDIX

A Guide to Riverine Substrate Particle Scale (Gerber and Gabriel, 2002).

<table>
<thead>
<tr>
<th>Category</th>
<th>Substrate size range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silt</td>
<td>&lt; 0.06 mm</td>
</tr>
<tr>
<td>Sand</td>
<td>0.06 – 2 mm</td>
</tr>
<tr>
<td>Gravel</td>
<td>2- 20 mm</td>
</tr>
<tr>
<td>Stones</td>
<td>2- 30 cm</td>
</tr>
<tr>
<td>Boulders</td>
<td>&gt;30 cm</td>
</tr>
<tr>
<td>Bedrock</td>
<td>Slabs of rock</td>
</tr>
</tbody>
</table>