

**EFFECTS OF WEIR INSTALLATION ON WATER QUALITY AND
MACROINVERTEBRATE COMMUNITY STRUCTURE OF TWO RIVERS IN LAKE
VICTORIA BASIN, KENYA**

AMADI JACINTER ALUOCH (B.ed)

I56/10126/2008

**A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR
THE AWARD OF THE DEGREE OF MASTER OF SCIENCE (ANIMAL ECOLOGY)
IN THE SCHOOL OF PURE AND APPLIED SCIENCES OF KENYATTA
UNIVERSITY**

JUNE 2012

DECLARATION

I hereby declare that this thesis is my original work and has not been presented for degree or any other award in any other university.

Amadi Jacinter Aluoch
Zoological Sciences Department

Signature..... Date.....

This work has been submitted with our approval as supervisors:

Dr. Benson M. Mwangi
Department of Zoological Sciences
Kenyatta University

Signature..... Date.....

Dr. John W. Gichuki
Kenya Marine and Fisheries Research Institute
Kisumu Research Center

Signature..... Date.....

DEDICATION

To my son, John Derrick.

ACKNOWLEDGEMENTS

The success of this study is a product of the participation of many individuals. I am thankful to Dr. B.M. Mwangi of Zoological Sciences, Kenyatta University who conscripted me into the Vicres research project, Kisumu. His Professional guidance and insights in this work was immense.

I am also grateful to Dr. John W. Gichuki, immediate former centre director, Kenya Marine and Fisheries Research Institute (KMFRI) Kisumu, who not only authorised me to use KMFRI facilities during research but also agreed to be my supervisor. I am equally thankful to the technical staff of the same institution that assisted me during sample collections and laboratory analyses.

Further, I sincerely appreciate the support offered to me by Kenyatta University in form of a scholarship during my course work.

Finally, I feel deep sense of gratitude to my sister Phoebe, for her purity of soul, my parents for their constant love and Dickson, for his advices, encouragements and support.

TABLE OF CONTENT

DECLARATION.....	ii
DEDICATION.....	iii
ACKNOWLEDGEMENT.....	iv
TABLES OF CONTENT.....	v
LIST OF TABLES.....	viii
LIST OF FIGURES.....	x
LIST OF PLATES.....	xii
LIST OF ABBREVIATIONS.....	xiii
ABSTRACT.....	xiv
CHAPTER ONE: INTRODUCTION.....	1
1.1 Background information.....	1
1.2 Justification and statement of the problem.....	3
1.3 Research questions.....	3
1.4 Hypotheses.....	3
1.5 Objectives.....	4
1.5.1 General objectives.....	4
1.5.2 Specific objectives.....	4
CHAPTER TWO: LITERATURE REVIEW.....	5
2.1 Macroinvertebrates and riverine productivity.....	5
2.2 Effect of weirs on macroinvertebrate diversity.....	5
2.3 Effect of substrate composition on macroinvertebrates.....	6
2.4 Effect of weirs on water quality.....	7
2.5 Effect of weirs on stream morphology and hydrology.....	8
CHAPTER THREE: MATERIALS AND METHODS.....	10
3.1 Description of study sites.....	10
3.1.1 River Kisian.....	10
3.1.2 River Awach- seme.....	14
3.2 Research and sampling design.....	17
3.3 River Depth and velocity.....	18
3.4 Assessment of water quality.....	18

3.4.1 Physical parameters.....	18
3.4.2 Chemical parameters.....	18
3.4.3 Nutrients.....	19
3.5 Substrate analysis.....	19
3.6 Macroinvertebrate sampling.....	19
3.7 Data analysis.....	20
CHAPTER FOUR: RESULTS.....	21
4.1 Physical and chemical characteristics of water between Rivers Kisian and Awach-seme.....	21
4.1.1 Water depths.....	21
4.1.2 Water temperature.....	22
4.1.3 Flow rate.....	24
4.1.4 Dissolved oxygen.....	27
4.1.5 Conductivity.....	29
4.1.6 Water pH.....	30
4.2 Nutrients.....	32
4.2.1 Nitrates.....	32
4.2.2 Soluble reactive phosphates.....	36
4.2.3 Silicates.....	39
4.2.4 Turbidity.....	40
4.2.5 Total dissolved solids.....	43
4.3 Bottom substratum.....	45
4.4 Macroinvertebrate communities.....	47
4.4.1 Composition and density of benthic macroinvertebrates.....	47
4.4.2 Temporal variation in macroinvertebrate densities.....	49
4.4.3 Macroinvertebrate species diversity, richness and evenness.....	51
4.4.4 Macroinvertebrate distribution.....	54
4.4.5 Effects of physical and chemical characteristics on macroinvertebarte Densities.....	54
CHAPTER FIVE: DISCUSSION.....	56
5.1 Effect of boulder weir installation on physico-chemical parameters at Kisian and	

Awach-seme Rivers	56
5.2 Effect of boulder weir placement on nutrients at Kisian and Awach-seme Rivers..	58
5.3 Effect of boulder weirs on bottom substratum.....	60
5.4 Effect of boulder weirs on composition, density and diversity of benthic invertebrates.....	61
CHAPTER SIX: CONCLUSIONs AND RECOMMENDATIONS.....	64
6.1 Conclusions.....	64
6.2 Recommendations.....	64
REFERENCES.....	65
APPEDICES.....	71
Appendix I.....	73

LIST OF TABLES

Table 1 Mean water depths (cm) and their ranges at Rivers Kisian and Awach-seme prior to weir installation, August to October 2009.	21
Table 2 Water depths (cm) before and after weir installation at Rivers Kisian (KS2) and Awach-seme (AS1 and AS2).	22
Table 3 Mean water temperatures (°C) at three sampling sites (upstream, midstream and downstream) along Rivers Kisian and Awach-seme, Lake Victoria Basin.	23
Table 4 Water temperature at River Kisian (KS2) and Awach-seme (AS1 and AS2) after weir construction.	24
Table 5 Mean flow rate and their ranges at Rivers Kisian and Awach-seme prior to weir installation.	25
Table 6 Mean flow rate at Rivers Kisian (KS2) and Awach-seme (AS1 and AS2) before and after weir installation.	26
Table 7 Mean dissolved oxygen (mg/l) and their ranges at three sampling sites along Rivers Kisian and Awach-seme prior to weir installation.	27
Table 8 Mean dissolved oxygen at Rivers Kisian (KS2) and Awach-seme (AS1 and AS2) after weir installation.	28
Table 9 Mean conductivity (µs/cm) and their ranges at Rivers Kisian and Awach-seme prior to weir installation.	29
Table 10 Conductivity at Rivers Kisian (KS2) and Awach-seme (AS1 and AS2) before after weir installation.	30
Table 11 Mean water pH and their ranges at Rivers Kisian and Awach-seme before weir installation.	31
Table 12 Water depths before and after weir installation at River Kisian (KS2) and Awach-seme (AS1 and AS2).	31
Table 13 Mean nitrate concentrations and their ranges at Rivers Kisian and Awach-seme prior to weir construction.	33
Table 14 Nitrate concentrations before and after weir installation at Rivers Kisian (KS2) and Awach-seme (AS1 and AS2).	35
Table 15 Mean Soluble reactive phosphate concentrations (µgP/l) and their ranges at Rivers Kisian and Awach-seme prior to weir installation.	36

Table 16 Soluble Reactive Phosphate concentrations ($\mu\text{gP/l}$) before and after weir installation at River Kisian (KS2) and Awach-seme (AS1 and AS2).....	38
Table 17 Mean silicate concentration (mg/l) and their ranges at Rivers Kisian and Awach-seme during the pre-weir period.	39
Table 18 Mean silicates (mg/l) before and after weir installation at Kisian (KS2) and Awach-seme (AS1 and AS2).	40
Table 19 Mean turbidity (NTU's) and their ranges at Kisian and Awach-seme Rivers before weir installation.....	41
Table 20 Turbidity (NTU's) before and after weir construction at Kisian (KS2) and Awach-seme (AS1 and AS2) Rivers.	42
Table 21 Mean TDS and their ranges at Rivers Kisian and Awach-seme prior to weir installation.	44
Table 22 Mean TDS before and after weir installation at River Kisian (KS2) and Awach-seme (AS1 and AS2).....	44
Table 23 Relative density of different macroinvertebrate taxa present at Rivers Kisian and Awach-Seme prior to and after weir construction, Lake Victoria Basin, Kenya.	48

LIST OF FIGURES

Figure 1 Map of Kenya showing sampling sites.....	11
Figure 2 Mean water depth recorded at sites KS2 (Kisian), AS1 and AS2 (Awach-seme) during the study period, August 2009 to July 2010.	23
Figure 3 Water temperature (mean \pm SE) at Kisian (KS2) and Awach-seme (AS1 and AS2) Rivers during the study period.....	24
Figure 4 Flow rate recorded at sites AS1, AS2 and AS3 in River Awach-seme before weir installation.....	26
Figure 5 Flow rate (mean \pm SE) recorded at Kisian and Awach-seme Rivers during the study period.	27
Figure 6 Mean dissolve oxygen at Kisian and Awach-seme Rivers during the study period.	28
Figure 7 Mean conductivity at Rivers Kisian and Awach-seme during the study period.	30
Figure 8 Mean water temperature at Kisian and Awach-seme Rivers during the study period. ..	32
Figure 9 Nitrate concentration between sites KS1, KS2 and KS3 at River Kisian during the pre-weir period.....	33
Figure 10 Nitrate concentration at Awach-seme River (AS1, AS2 and AS3) before weir installation.....	34
Figure 11 Nitrate concentration at River Kisian during the Pre-weir and Post-weir periods.	35
Figure 12 Nitrate concentration between Kisian and Awach-seme Rivers during the study period, August 2009 to July 2010.	36
Figure 13 Phosphate concentration at Kisian River before weir installation.....	37
Figure 14 Phosphate concentration between Kisian and Awach-seme Rivers during the study period.	38
Figure 15 Silicate concentration in between river Kisian and Awach-seme during the sampling period.	40
Figure 16 Turbidity at River Kisian (KS2) before and after weir installation.....	42
Figure 17 Turbidity between River Kisian and Awach-seme during the the sampling period, august 2009 to July 2010.	43
Figure 18 Total dissolved solids at Kisian and Awach-seme rivers during the study period.	45
Figure 19 Bottom substratum of Kisian and Awach-seme Rivers prior to weir construction.	46

Figure 20 Bottom substratum of Kisian (KS2) and Awach-seme (AS1 and AS2) Rivers after weir construction.....	46
Figure 21 Macroinvertebrate density between Rivers Kisian and Awach-Seme during the study period.	50
Figure 22 Macroinvertebrate density (indiv./m ²) at three sites along River Kisian before weir construction.....	50
Figure 23 Macroinvertebrate density (indiv./m ²) at three sampling sites along River Awach-seme prior to weir installation.	51
Figure 24 Macroinvertebrate species diversity at Rivers Kisian and Awach-Seme prior to and after weir construction.	52
Figure 25 Macroinvertebrate species richness at Rivers Kisian and Awach-seme prior to and after weir construction.	53
Figure 26 Macroinvertebrate species evenness at Rivers Kisian and Awach-seme prior to and after weir construction.	53
Figure 27 PCA analysis of physical-chemical parameters and macroinvertebrate taxa for the sampling period August 2009 – July 2010 (all samples on any date combined).	55

LIST OF PLATES

Plate 1. Photograph of Kisian River upstream site KS1	12
Plate 2. Photograph of Kisian River mid-sampling site KS2.....	13
Plate 3. Photograph of Kisian River lower sampling site KS3	14
Plate 4. Photograph of upper Awach-seme site AS1	15
Plate 5. Photograph of Awach-seme River mid-sampling site AS2	16
Plate 6. Photograph of Awach-seme lower sampling site AS3,	17
Plate 7. Gabion weir constructed at Mid-sampling site in Kisian River ,.....	71
Plate 8. Boulder weir at Upper Awach-seme	72
Plate 9. Boulder weir at mid Awach-seme.....	72
Plate 10. Human activities that negatively impact on the ecosystems of both Kisian and Awach-seme Rivers.....	73

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CPOM	Coarse Particulate Organic Matter
D.O.	Dissolved Oxygen
E	Species Evenness
FPOM	Fine Particulate Organic Matter
GPS	Global Positioning System
H'	Shannon-Weinner Diversity Index
KMFRI	Kenya Marine and Fisheries Research Institute
N	Nitrogen
NTU	Nephelometric Turbidity Units
P	Phosphorus
PCA	Principal Components Analysis
S	Species Richness
SRP	Soluble Reactive Phosphates
TDS	Total Dissolved Solids

ABSTRACT

Riverine benthic communities play a crucial role in trophic relationships by providing major sources of energy to economically and ecologically important fishes. With the declining production of the Lake Victoria fisheries, the importance of surrounding rivers as sources of fish will continuously increase. There is therefore need to refocus the management of the riverine ecosystems in order to improve their fisheries production, particularly concerning their natural fish food production. Understanding the benthic invertebrate community dynamics and their responses to newly introduced management interventions such as weirs is key towards improving the riverine fisheries production. This study therefore aimed at assessing the benthic invertebrate composition, diversity and density in two small Lake Victoria Basin rivers (River Awach-sume and Kisian) before and after weir installation in order to establish the possible impacts of such management interventions on the benthic invertebrate community. Prior to weir installation, three sampling sites were selected along each river, representing the upper reaches (KS1 and AS1; KS- River Kisian, AS-River Awach-sume), middle (KS2 and AS2) and lower reaches (KS3 and AS3). Pre-weir sampling was carried fortnightly between August and October 2009 while post-weir sampling was carried out monthly between December 2009 and July 2010. Quantitative benthic invertebrates were sampled using a Hess sampler (100 μ m). During every sampling, measurements of flow rate, water depth, temperature, dissolved oxygen, pH, conductivity, silicates, nitrates, phosphates and totals dissolved solutes were taken. Results showed that the two rivers to have similar physical and chemical characteristics, except for conductivity and silicates that differed significantly. Physico-chemical parameters, including dissolved oxygen, nitrates and turbidity, however differed significantly ($p < 0.05$) among sites within Kisian River. Installation of weirs had insignificant impact on the physico-chemical parameters except nitrates that decreased significantly at both rivers while turbidity decreasing only at Kisian River Site KS2. Benthic invertebrate community at all sites was largely dominated by chironomidae before and after weir installation followed by the Ephemeroptera, particularly the genus *Baetis* sp. 26 genera were obtained at River Awach-sume while 23 at River Kisian before weir installation, 25 and 17 were obtained after weir installation respectively. Macroinvertebrate densities were significantly higher at Awach-sume. Density increased steadily during pre-weir period in both rivers, but declined though not significantly after weir installation. There were no significant differences in density among sites at any of the two rivers.

Macroinvertebrate Diversity (H') did not differ significantly among sites and within rivers before and after weir installation. PCA analysis showed TDS and conductivity to be closely related to macroinvertebrate densities. Mean water depth at upper Awach-eme showed a significant negative correlation with density. Other parameters were not significantly related to density. Most physical and chemical variables as well as benthic invertebrate density and diversity were observed to be unaltered by weir installation. These results did not support the hypothesis that weirs induce an improvement in the quality of in-stream habitats and change in benthic invertebrate communities. This research therefore provides baseline data for further action.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Throughout much of the world, streams have been degraded by anthropogenic stresses including channelization, removal of riparian vegetation, agricultural and industrial pollution, hydrologic alterations, inappropriate land-use practices (Van Zyll De Jong *et al.*, 1997; Roni *et al.*, 2006; Reich *et al.*, 2009) and overpopulation (Brooks *et al.*, 2002). These activities can affect the distribution, survival and production of fish and other aquatic organisms, disrupt community structure and cause the loss and degradation of critical habitats (Van Zyll De Jong *et al.*, 1997). Channelization decreases habitat for aquatic organisms by increasing peak stream flow and reducing benthic substrate heterogeneity (Litvan *et al.*, 2008). Sediments from overland runoff and within channel erosion bury natural rocky substrates and in so doing reducing habitats for aquatic organisms (Litvan *et al.*, 2008).

In response to deteriorating conditions of streams, many rehabilitation projects use in-stream structures such as boulder weirs, artificial riffles, check dams and flow deflectors to increase habitat heterogeneity and reduce stream-bank erosion (Comiti *et al.*, 2009). River regulation using weirs has been used in many streams in North America, Europe, Australia and elsewhere (Gore and Hamilton, 1996; Fleituch, 2003; Harrison *et al.*, 2004; Armitage, 2006; Roni *et al.*, 2006; Balcombe *et al.*, 2007; Almeida *et al.*, 2009). Weirs or low head dams 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 dam used to maintain the vertical profile of a stream or channel. A weir artificially reduces the upstream water velocity, thus can lead to an increase in siltation, pose a barrier to migrating fish and increases the oxygen content of the water as it passes over the crest.

The effect of river regulation on the biota varies according to the structural features of the impoundment, its purpose and operation. There are several ways in which flow modification in regulated rivers cause ecological effects; decreased local current velocities, decreased overall stream habitat, increased siltation of stream bed, altered flow patterns, altered thermal and sediment regimes and changes in substrate condition (Growth and Growth, 2001; Collier, 2002).

Environmental factors such as flow variability, depth, canopy cover, food supply and water chemistry influence the composition, structure and distribution of stream invertebrate communities (Humphries *et al.*, 1996; Rader and Belish, 1999; Gonzalez and Graca, 2005; Kominoski and Pringle, 2009).

Benthic communities play a critical role in trophic relationships by providing major sources of energy to economically and ecologically important fishes (Ansari *et al.*, 2003). As processors of organic matter and as primary food for fish, aquatic macroinvertebrates, are crucial to nutrient cycling and energy flow just like the riparian vegetation (Rader and Belish, 1999; Tonkin *et al.*, 2009). Macroinvertebrate detritivores are dominant contributors to litter breakdown in streams and are prey to several levels of predators in aquatic ecosystems (Kominoski and Pringle, 2009). Their diverse morphology and ability to adapt to various habitats make them important as food for large benthic organisms and in recirculation of nutrients.

The abundance of benthic invertebrates in an area is related to its environment and reflects the characteristics of an ecological niche (Ansari *et al.*, 2003). The construction of weirs may cause isolation of some populations (Pohlon *et al.*, 2007), local extinction or fostering of some species and promote the invasion and the success of exotic species (Almeida *et al.*, 2009). The most common in-stream structures such as dams, weirs, bank covers and boulder placements modify local hydraulic conditions to present preferred habitat to benthic invertebrates (Gore *et al.*, 1998). Benthic invertebrates readily colonize boulders placed in streams, and achieve relatively high levels of abundance and diversity because of increased habitat surface area and complexity offered by these substrates (Litvan *et al.*, 2008).

Studies involving the impact of water barriers on freshwater invertebrates have been carried out in dams (Collier, 2002; Zhou *et al.*, 2008; Almeida *et al.*, 2009; Svendsen *et al.*, 2009). However, weirs have received relatively little attention, especially in Africa although such structures can produce relatively large amounts of fish if well managed. This study focused on assessing the benthic invertebrate community composition, diversity and density in two Lake Victoria Basin rivers, Awach-sume and Kisian before and after weir installation in order to establish the possible impacts of such management interventions on the benthic invertebrate community.

1.2 Justification and statement of the problem

Declining capture fisheries calls for diversified fish sources, such as riverine fishes. To improve riverine fish production, there is need to institute a management structure focusing on key fish food sources, particularly the benthic invertebrates. In Lake Victoria, fish production has been declining (Cowx *et al.*, 2003; Odada *et al.*, 2004; Matsuishi *et al.*, 2006), hence need to improve riverine fish production. There is therefore need to understand the benthic invertebrate community in order to institute appropriate riverine management structures such as weirs. Boulder weirs modify local conditions presenting preferred habitat to benthic macroinvertebrates. They create greater habitat complexity, increase variability in depth, substrate, cover and current velocity. The improved habitat conditions can lead to high levels of density and diversity of macroinvertebrate species and other benthic organisms. These changes may have a positive influence on the fisheries productivity potential of the streams through increased energy transfer in riverine food webs. Such impacts are likely to flow through to fish, further increasing their diversity and production. Consequently, fisheries production would increase; more proteins would be available and employment opportunities would increase.

1.3 Research questions

- i. How does the macroinvertebrate community structure and water quality of the two streams compare?
- ii. What is the effect of boulder weir on macroinvertebrate communities and water quality characteristics?

1.4 Hypotheses

- i. There is no significant difference in the macroinvertebrate community structure and water quality status between Rivers Awach-sume and Kisian.
- ii. Boulder weirs do not affect the water quality and macroinvertebrate community of Rivers Awach-sume and Kisian.

1.5 Objectives

1.5.1 General objective

To investigate the effect of boulder weir on benthic macroinvertebrate communities of Rivers Awach-sume and Kisian.

1.5.2 Specific objectives

- i. To assess the macroinvertebrate community structure of Rivers Awach-sume and Kisian before and after weir installation.
- ii. To determine water quality of Rivers Awach-sume and Kisian before and after weir installation.
- iii. To assess the relationship between water quality and macroinvertebrate community structures

CHAPTER TWO: LITERATURE REVIEW

2.1 Macroinvertebrates and riverine productivity

Macroinvertebrates are a critical link in aquatic food webs and play a vital role in stream ecosystem function (Litvan *et al.*, 2008). Macroinvertebrates increase nutrient cycling- and energy-transfer efficiencies through aquatic food webs by consuming and physically breaking down periphyton and detritus, and subsequently excreting nutrients and serving as prey for vertebrates (Litvan *et al.*, 2008). By consuming primary producers and decomposing organic matter, and in turn serving as prey for vertebrates, aquatic macroinvertebrates function as conduits of energy and nutrients to organisms at higher trophic levels (Litvan *et al.*, 2008).

2.2 Effects of weirs on macroinvertebrate diversity

Benthic invertebrates readily colonize boulders placed in streams, and achieve relatively high levels of abundance and diversity because of increased habitat surface area and complexity offered by these substrates (Litvan *et al.*, 2008). The most common structures for fish habitat enhancement have been current deflectors, over pour structures (dams and weirs), bank cover and boulder placements. Those in-stream structures modify local hydraulic conditions presenting preferred habitat to benthic invertebrates (Gore *et al.*, 1998). For macroinvertebrates, the primary considerations include formation of sediment-free riffle areas and structures to control sediment deposition (Gore *et al.*, 1998). According to Van Zyll De Jong *et al.* (1997) addition of boulders creates greater habitat complexity, increasing variability in depth, substrate, cover and current velocity.

Boulder weirs are widely used in stream management to create habitat for organisms and to reduce stream bank erosion. They stimulate increases in density and diversity of macroinvertebrates and other benthic organisms and improve ecosystem health in streams and rivers (Litvan *et al.*, 2008). Fjellheim and Raddum (1996) indicated that weirs create a greater and more stable water volume, which may be of benefit to many stream animals, including fish. Comiti *et al.* (2009) suggested that boulder weirs featured the highest macroinvertebrate density in both pools and runs possibly because bed geometry, sediment size and morphology presented a hydraulically milder physical environment than a natural pool channel. However, the

hydrophysical conditions after building such small impoundments are greatly altered compared to the pre-regulation situation. Harrison *et al.* (2004) pointed out that physical changes associated with boulder weir placements reduce diversity, density and biomass among invertebrate, particularly those species associated with coarse substrata, shallow water, high velocity and complex riparian habitats.

2.3 Effects of substrate composition on macroinvertebrates

Aquatic invertebrates are associated with a wide variety of substrates, ranging from dead wood, all sizes of inorganic particles (silt, sand, gravel and cobbles) (Gore *et al.*, 1998) to macrophyte beds (Humphries *et al.*, 1996). Substrate in particular, is a primary determinant of community structure, with taxa richness and total macroinvertebrate abundance often increasing with increased habitat heterogeneity (Litvan *et al.*, 2008).

Substrate composition is the most easily manipulated habitat characteristic in restoration projects (Gore *et al.*, 1998). Highest diversities and production have been reported from channels with medium cobbles (256mm diameter) and gravel substrates (Gore *et al.*, 1998). Studies in regulated rivers with reduced flow indicate a positive effect of coarse substrate on the density and biomass of many benthic species (Fjellheim, 1996; Negishi and Richardson, 2003). However, benthic invertebrate distribution is also dependent on biotic factors, competition, predation and food availability (Fjellheim, 1996).

Litvan *et al.* (2008) suggested that by increasing local substrate size and heterogeneity, artificial riffles could benefit aquatic organisms, including benthic macroinvertebrates, by producing additional habitat in degraded streams dominated by soft substrate. Riffles also represent an important habitat for the production of fish food. Hence, when planning weir construction it is important to secure reasonably alternating riffles and pools. Such alternations of different habitats increase benthic animal diversity (Fjellheim and Raddum, 1996).

In lentic and lotic ecosystems, rocks, woody debris and variety of other structurally complex substrates usually support higher macroinvertebrate abundance and diversity than finer substrates (Litvan *et al.*, 2008). Studies by Harrison *et al.* (2004) and Comiti *et al.* (2009) reported that coarser units characterized by fast-flowing water such as riffles and runs present higher macroinvertebrate diversity and density than deeper, slower areas covered with finer sediments such as pools. Relative to fine, soft substrates, both natural and artificial coarse substrates provide greater surface area for colonization, reduce likelihood of localized extinctions due to chance (Litvan *et al.*, 2008) and offer more profitable foraging sites (Harrison *et al.*, 2004). In streams, heterogeneous habitats created by coarse substrates support taxa with diverse requirements, and provide refuges from predation and shear forces caused by floods (Harrison *et al.*, 2004). Additionally, coarse substrates trap drifting coarse particulate organic matter (CPOM), increasing availability of food and habitat for macroinvertebrates (Litvan *et al.*, 2008). Increasing amounts of organic detritus on the bottom lead to increases in the numbers of certain species, including *Baetis* (Fjellheim, 1996). By retaining CPOM and increasing its residence time in streams (Pohlon *et al.*, 2007), coarse substrates enable macroinvertebrates to colonize and process this material (Litvan *et al.*, 2008). Coarse particulate organic matter degraded into fine-particulate organic matter (FPOM) by shredding macroinvertebrates can be assimilated locally by filter-feeding and collector-gathering macroinvertebrates (Litvan *et al.*, 2008).

2.4 Effects of weirs on water quality

Weir reservoirs create distinct physical conditions, which differ considerably from free-flowing natural reaches but chemical and thermal differences often occur only locally (Pohlon *et al.*, 2007). Nutrient concentrations in streams vary through time in response to numerous factors, including discharge, temperature, evaporation, and biogeochemical transformations (McNamara *et al.*, 2008). Nitrogen (N) and phosphorus (P) loadings to aquatic ecosystems are often dominated by anthropogenic inputs including, synthetic fertilizers, manure, detergent sources and sewage (Heathwaite *et al.*, 1996; Shields Jr *et al.*, 2009). The level of nutrient loading, both spatial and temporal, from a variety of sources affects the magnitude of change in water quality (Heathwaite *et al.*, 1996).

Roni *et al.* (2006) reported improvements in physical habitat following treatments and that boulder weir had no effect on water chemistry and nutrient levels (N, P). Fjellheim and Raddum (1996) demonstrated that weir basins had a high ecological importance in rivers with reduced discharge. The basins delay the downstream transport of organic material, thereby making more energy available to detritus feeders in the river. A system of weir basins that is too dense will trap detritus and drifting invertebrates and may act negatively towards downstream productivity (Fjellheim and Raddum, 1996).

Temperature is a strong driver of seasonal distribution and density of invertebrates (Balcombe *et al.*, 2007). It greatly influences riverine fishes, and particularly warm water fishes (Jackson and Marmulla, 2000). Temperature change due to river regulation has broad ecological consequences, affecting drift pattern, growth rates, life histories and densities (Fjellheim, 1996). Weirs can alter water temperature, discharge volume and sediment deposition (Tonkin *et al.*, 2009). Conductivity indicates primarily the concentrations of main cations (Ca, Mg). It relates to water pH, an important variable for aquatic biota (Soininen, 2004).

Wood and other channel obstructions that trap gravel and organic matter within boulder weirs lead to changes in water chemistry (Roni *et al.*, 2006). The quantity and quality of epiphytic food resources also influence the structure of invertebrate assemblages (Balcombe *et al.*, 2007).

2.5 Effects of weirs on stream morphology and hydrology

Changes in stream morphology (canalization and dredging) and hydrology (flow regulation) 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).

According to Grown and Grown (2001), flow management in regulated rivers should take into account the animals in different habitat types, particularly for low flow habitats. Collier (2002) reported that the degree of flow regulation has a secondary effect on invertebrate community. Low flow periods often result in an increase in taxa that are suited to low velocity, high periphyton biomass conditions to the detriment of mayflies and caddisflies (James *et al.*, 2008). Reduced flow alters the in-stream environment by decreasing flow velocity, depth, wetted width and taxonomic richness. It also increases sedimentation and alters invertebrate densities and community composition (James *et al.*, 2008). Such changes can directly or indirectly influence the drift behavior of benthic invertebrates. Rivers subject to severe low flow and increased sedimentation are characterised by a low diversity of macroinvertebrates (Wood and Armitage, 1999). Flow velocity has significant impacts on the density of riverine invertebrates (Wood and Armitage, 1999).

Increased flow in some regulated rivers lead to higher current velocities, which may in turn scour the bed, resulting in a change to a coarse substratum (Grown and Grown, 2001). Complex flow conditions, incorporating factors of depth, velocity, bed roughness and viscosity of the water, are predictors of benthic densities and perhaps, fish population responses (Gore *et al.*, 1998). These factors are the main conditioners of structural and functional alterations in the aquatic biota (Almeida *et al.*, 2009). According to Balcombe *et al.* (2007), depth is the most important parameter influencing invertebrate distribution and density. Flow alterations and weirs that reduce discharge and affect temperature, hydraulics, substrate, periphyton (microphytes) and invertebrates in large rivers might also alter benthic macroinvertebrate communities in small streams.

The integrity of river ecosystem relies on a balance among all physical, chemical and biological factors, which operate in conjunction with each other to produce unique systems (Fleituch, 2003). Boulder weirs may positively influence benthic macroinvertebrate diversity and density, further enhancing the integrity and diversity of these crucial ecosystems.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of study sites

Rivers Kisian and Awach-seme are third and fourth order streams located at latitudes 0° 00' S, 34° 34' E and 0° 07' S, 34° 44' E, respectively (Figure 1). Originating from Maragoli Hills in Vihiga County, these rivers are part of the lower catchments of Lake Victoria. They drain a watershed of 165 km². The altitude ranges from 1190 to 1485m above sea level generally sloping from North to South. The area receives a bimodal rainfall pattern with one short season from October to December and a long rainy season from March to July. The mean annual rainfall ranges from less than 1000mm near the shores of Lake Victoria to 1,900mm in hilly areas of Maragoli. The geological formation is composed of the Kavirondian and Nyanzian rock systems with high potential for ballast and building stone. Land use in the catchments is dominated by agriculture with about 75% of the total area considered arable (Government of Kenya, 2002) and small-scale livestock production (Amadalo *et al.*, 2003). Most of the natural vegetation has disappeared because of intensive agricultural activities. The catchment has a low forest cover (about 4%) which is an extension of the expansive Kakamega forest (Government of Kenya, 2002). The rivers were selected *a priori* based on the local knowledge of fish occurrence, their sizes and consent of the local people. These rivers were not expected to differ markedly in biodiversity and major environmental variables such as hydrology, water temperature and chemistry. GPS coordinates were recorded at each sampling site using Garmin 12 hand-held GPS receiver.

3.1.1 River Kisian

Three sites were selected along Kisian River representing the upstream (KS1, 00° 02' 294", 34° 40' 859"), midstream (KS2, 00° 04' 274", 34° 40' 045") and downstream (KS3, 00° 04' 787", 34° 40' 488"). The upper reaches site (KS1; Plate 1) are largely well vegetated at least for about 5-10 metres on either side of the bank. It is an extensive pool covered by riparian vegetation on either side. The reach width ranges from 4.1 to 6.8m and length of 10m for all sites. Both banks are steep and covered by plants such as *Phragmites* sp., *Tithonia diversifolia*, *Lantana camara* and *Musa domestica* amongst other minor species. The bottom substratum comprises silt mixed with a few cobbles. Main agricultural activities along the riverbanks include extensive crop cultivation and small-scale animal rearing. Crops include maize, sorghum and banana plantations

near the riverbanks had replaced majority of native riparian vegetation. Anthropogenic activities taking place at this sampling site include sand harvesting, domestic washing and poor agricultural methods along the riparian zone. Although most of indigenous riparian vegetation has been removed, small amount of remnant exists.

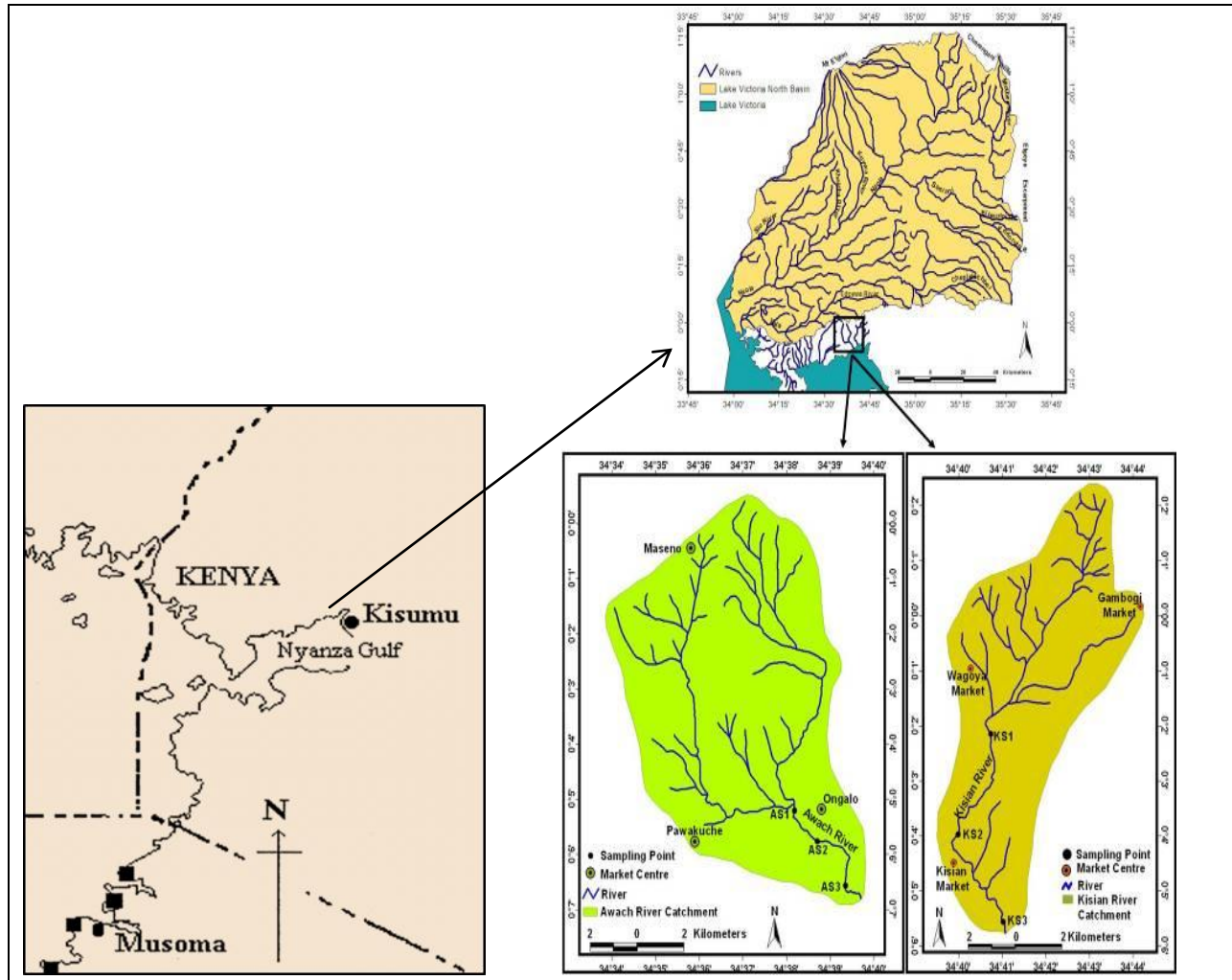


Figure 1. Map of Kenya showing sampling sites.

Rock outcrops, shallow pools and numerous riffles (Plate 2) characterized the midstream section of the river (KS2). The reach width ranges from 5.6 to 10.7m with 65% boulders and cobbles as bottom substrate. The right riverbank is relatively open, gentle slopping and bordered small-scale farms in which the soil is bare in most cases. The right riverbank is well covered with riparian vegetation mainly *Phragmites* and Eucalyptus trees that protects the riverbank from erosion. At

this sampling site, domestic washing and car washing are the main anthropogenic activity observed. Agricultural activities along the riverbanks included small-scale farms and animal rearing.



Plate 1: Photograph of Kisian River upstream site (KS1) showing dense riparian vegetation overhanging the river.



Plate 2: Photograph of Kisian River mid-sampling site (KS2) showing the huge boulders characterizing the basement rock. The site is also covered by dense vegetation.

The lower reaches of Kisian River (KS3) (Plate 3) has the least vegetation cover with intense human activities along banks. The riparian vegetation is largely dominated by *Phragmites* mixed with other grass species. This site has a narrow river width ranging from 2.9 to 5.7m. Bottom substratum consist mainly of sand and silt mixed in almost equal proportion. This site lacks larger substratum like gravel, cobbles or boulders that are important to benthic invertebrates. This site is disturbed by human activities like sand harvesting, watering animals and other domestic uses like recreation. The land along the river banks is fragmented and used for crop production where crops like maize, cassava, beans and bananas are grown. Horticultural crops like vegetables and tomatoes are also observed along this site. Human settlement along the riparian zone led to clearing of the vegetative cover in these areas to provide room for constructing houses and crop cultivation. Generally, the river flows through open areas that cause occasional flooding when it rains.



Plate 3: Photograph of Kisian River lower sampling site (KS3) showing exposed and eroded riverbanks and sand as the main bottom substratum. The left bank is bare while the right bank has sparse plant cover.

3.1.2 River Awach-seme

Three sites were also selected along River Awach-Seme AS1 (00° 05' 477", 34° 28' 577") representing the upper reaches, mid-reaches (AS2, 00° 05' 751", 34° 28' 480") and lower reaches (AS3, 00° 06' 714", 34° 28' 387"). The upper reaches of the river is typically a shallow area covered with few boulder outcrops that form runs (Plate 4). The bottom substratum comprises gravel mixed with cobbles and a few boulders. The bottom substratum type leads to the formation of numerous riffles within river channel. Reach width ranges from 5.8 to 13.3m and relatively undisturbed. Riparian buffer is co-dominated by *Phramites* Sp. and *Tithonia diversifolia* protecting both banks up to about 4 metres. Small scale agricultural farms where maize is the main crop cultivated border these buffer strips. Some sections of the riverbank lack riparian vegetation; instead, they are replaced by crop farms. Animal watering, domestic washing and mining of sand and gold are observed on the upper side of the site.



Plate 4: Photograph of upper Awach-seme (AS1) showing the riparian vegetation cover with *Phragmites* and *Tithonia diversifolia*, boulder outcrops resulting in formation of numerous runs and riffles.

Mid-reaches of River Awach-Seme (AS2, Plate 5) is characterized by both riffles and pools. The bottom substratum comprises boulders and cobbles mixed with some silt. The reach width ranges from 4.6 to 11.3m. The right riverbank is more covered than the left riverbank having mainly short *Phragmites* sp. as the dominant vegetation cover, whereas the left river bank is bordered by plant species including; *Aloe*, *Lantana camara*, *Euphorbia tirucalli* and open grassland. Bordering the riparian vegetation to the right are crop farmlands. The river has a narrow width about 4.8 meters with a wider bank flow width varying with hydrology. Agricultural activities taking place along this sampling site comprise crop farming and small-scale animal keeping. Anthropogenic activities like; poor agricultural activities, domestic washing and hunting of aquatic animals like otters are observed.



Plate 5: Photograph of Awach-seme River mid-sampling site (AS2) showing boulder outcrops and riparian vegetation cover consisting mainly of *Phragmites*.

Lower reaches of River Awach-seme (AS3) (Plate 6) consist of deep pools and shallow riffles. The reach width ranges from 3.3 to 9.6m. Extensive rock outcrop covers some sections of right riverbank. This site has varied habitats for benthic invertebrates, bottom substratum consist mainly of gravel mixed with sand. The riparian vegetation is dominated by herbaceous layer comprising *Phragmites* sp., *Mimosa* sp., *Tithonia diversifolia* mixed with some few but large *Ficus* trees. Both riverbanks are well covered by riparian vegetation of about 10 meters with no sign of crop farming at the site. There is some degree of soil erosion in open areas near the river depicted by the presence of gullies. Major anthropogenic activities near the sampling site include animal watering and domestic washing. There is no sign of crop cultivation at the vicinity of this site.



Plate 6: Photograph of Awach-seme River lower sampling site (AS3), riparian cover showing dense vegetation cover on the left riverbank.

3.2 Research and sampling design

Sampling was carried out before and after weir installation. Pre-weir sampling was carried out for two months from August to October 2009 whereas post-weir sampling was carried out for four months from December 2009 to July 2010 with exception of February, March and April due to the heavy rains that flooded the rivers. In November 2009, construction of boulder weirs was done. Systematic sampling design was used where samples were taken three points at each sampling site (half-meter from either banks and at the middle of the river course). This was done simultaneously from riffles and pools. Treatment was defined as artificial placement of boulder weir within an active stream channel. Large boulders were moved and placed across the rivers to create three weirs at Awach-seme River sampling sites AS1 and AS2 and Kisian River site KS2. This depended on the type of the river channel and availability of large rocks (boulders). A gabion weir was constructed at the mid reaches of river Kisian (KS2) since there were no enough boulders.

3.3 River depth and velocity

Depth was measured to the nearest centimetre at each sampling site. A subsurface float was used to measure discharge (Gordon *et al.*, 1992). This was done by observing the time required for floating object (half-filled bottle) to traverse a distance of 10 meters. The float was introduced upstream of the reach so it can attain the speed of the water before passing the first mark. A stopwatch was used to measure the time of travel between two marked sections. Three runs were made to obtain an average. The surface velocity was calculated as (V_{surface}).

$$V_{\text{surface}} = L/t$$

Where L= measured reach length in meters, t = travel time in seconds and V_{surface} was in m/s.

Bank flow width and river width were measured to the nearest metres using a tape measure.

3.4 Assessment of water quality

3.4.1 Physical parameters

Water quality parameters measured included temperature and turbidity. Water temperature was measured using a standard laboratory thermometer. Temperature distribution was determined by lowering the thermometer to a depth of about 10-15 cm at three representative horizontals across the river channel. Average temperature was calculated from the three readings. Turbidity was measured using Hach 2100P turbidimeter by filling a clean sample cell with a representative water sample. The sample cell was tightly capped and wiped. Turbidimeter was turned on and sample cell inserted into the sample compartment. The cover was closed and reading recorded.

3.4.2 Chemical parameters

pH was determined by a microprocessor pH meter. Conductivity measured by WTW microprocessor conductivity meter LF6. Dissolved Oxygen (D.O.) was determined by a calibrated sensitive electrode probe meter (Hanna). Probes for measuring these parameters were immersed into the water and allowed to stabilise, readings were then taken. TDS was measured using Hanna Hi 9034 TDS Meter. The meter probe was immersed in water beyond the vent holes and stirred to release any air trapped in the vent holes. It was turned on, once the reading had stabilized the measurement were taken.

3.4.3 Nutrients

Nutrient analysis was carried out fortnightly before and monthly after weir installation in the laboratory. Triplicate samples for nutrients (nitrate, silicate and phosphate) were collected filtered and analysed according to Wetzel and Likens (2000). Freshly collected water samples were filtered through membrane filters of 0.45 µm pore size. Nitrates were measured following the cadmium reduction method. Phosphate phosphorus was measured following the ascorbic acid method. Silicate was determined by the silicomolybdic method. Samples for water quality were collected before macroinvertebrate sampling to prevent contamination.

3.5 Substrate analysis

Substrate composition in each sampling site was visually classified as the proportion of each of the following substrate particle size classes: silt/clay/mud (< 0.0625mm diameter), sand (0.0625-2mm diameter), gravel (2mm-64mm diameter), cobble (64- 256 mm diameter) and boulders (256- 4096 mm diameter). Particle size analysis was applied to bed load sediment and bank materials. Substrate composition was quantified by assigning codes to substrate size classes in the following manner: 1 = silt, 2 = sand, 3 = gravel and 4 = cobble/ boulder. Proportion of each substrate type was determined at each sampling location (Gordon *et al.*, 1992; Litvan *et al.*, 2008).

3.6 Macroinvertebrates sampling

Each site was sampled on four occasions prior to weir introduction (fortnightly) and four occasions after weir construction (monthly). Sampling for macroinvertebrates was done where water samples had been collected. Macroinvertebrates were collected from three systematically selected locations (from pools and riffles) within each sampling reach using a Hess sampler (mesh net size 100 µm, area 0.028m²). Samples were transported in plastic vials, brought to the laboratory in a cooling box. In the laboratory samples were washed through series of sieves (smallest mesh size, 100 µm). All invertebrates were sorted to order level and preserved with 70% Ethanol for further identification to genus level according to Pennak (1978) and Merritt and Cummins (1996) and by the help of experts at KMFRI. Macroinvertebrates were counted using dissecting microscope and samples pooled to make one composite sample per site.

3.7 Data analysis

One-way Analysis of Variance (ANOVA) was used to determine differences in macroinvertebrate, physical and chemical parameters. ANOVA was used to test for any significant differences in density, diversity, physical and chemical parameters between sites before weir installation. Macro-invertebrate density (D) was estimated as,

$$D = N/0.028\text{m}^2,$$

Where D = number of individuals per m^2 of streambed area, N = total number of individuals and 0.028m^2 = Hess-sampled area.

Diversity was determined using Shannon index,

$$H' = - \sum ((n_i/N) \log_e (n_i/N)), \text{ (Shannon-weiner, 1949).}$$

Where H' = Shannon index of diversity, n_i = number of individuals for each taxon, N = total number of individuals and \log_e = natural log. Where differences were significant, post hoc analysis was carried out by means of Turkey's test. A t-test was used to determine differences before, after weir installation, and between the rivers. Multivariate relationships among physical and ecological variables were explored using Pearson's correlations and Principal Components Analysis (PCA) to determine physical-chemical features related to variation in macroinvertebrate densities, the probability value was at $P < 0.05$.

CHAPTER FOUR: RESULTS

4.1 Physical and chemical characteristics of water between Rivers Kisian and Awach-seme

4.1.1 Water depths

Water depths at River Kisian varied from a low of 22.7cm to a high of 66.00cm prior to weir installation at all sampling sites (KS1= Upstream; KS2=Midstream and KS3= Downstream). Mean water depths prior to weir installation did not differ significantly among sites ($F_{2,8} = 0.44$, $P > 0.05$; Table 1). At River Awach-seme, water depths ranged from a minimum of 17.7cm to a maximum of 40 cm prior to weir construction at the three sampling sites. Mean water depths did not differ significantly among the three sites ($F_{2,9} = 1.52$, $P > 0.05$; Table 1).

Table 1. Mean water depths (cm) and their ranges at Rivers Kisian and Awach-seme prior to weir installation, August to October 2009, n =9.

		<u>Water depths (cm)</u>			
		Upstream	Midstream	Downstream	Anova
R. Kisian	Mean \pm SE	46.13 \pm 8.64	36.40 \pm 5.46	32.10 \pm 12.66	0.44 ^{n.s}
	Ranges	24.50 – 66.00	22.70 - 47.70	24.00 – 55.00	
R. Awach-seme	Mean \pm SE	25.90 \pm 3.55	34.45 \pm 4.60	25.30 \pm 4.21	1.52 ^{n.s}
	Ranges	17.70 – 34.00	20.80 – 40.00	15.00 – 34.00	

n.s. non significant

At sites AS1 and AS2, water depths after weir installation ranged from 23.6 cm to 47.5 cm with means of 26.1 \pm 1.42 and 35.6 \pm 5.33, respectively (Table 2). Comparison of changes in water depths before and after weir construction showed no significant rise in water depths ($t = -0.13$; d.f = 3; $P > 0.05$). Similarly, water depths between sites AS1 and AS2 did not vary significantly after installing the weirs ($t = 1.96$; d.f = 3; $P > 0.05$; Figure 2). At Kisian River, water depths at midstream ranged from 33.3 to 68.5 cm with a mean of 49.9 \pm 8.33 (Table 2). Water depths at site KS2 did not differ significantly ($t = -1.46$; d.f = 3; $P > 0.05$) indicating a non significant rise (Figure 2). Water depths between the two rivers did not vary significantly before weir

installation ($t = 1.50$; $d.f = 3$; $P > 0.05$) but the variation increased significantly after weir installation ($t = 3.54$; $d.f = 3$; $P < 0.05$), probably because River Kisian being narrow resulted in greater water rise after weir installation.

Table 2. Water depths (cm) before and after weir installation at Rivers Kisian (KS2) and Awach-
seme (AS1 and AS2), $n = 4$.

	Mean water depths (cm) \pm SE		
	<u>River Kisian</u>	<u>River Awach-seme</u>	
	KS2	AS1	AS2
Before weir	36.40 \pm 5.46	25.90 \pm 3.55	34.50 \pm 4.60
After weir	49.90 \pm 8.33	26.20 \pm 1.42	35.60 \pm 5.33
Significance	$P > 0.05$	$P > 0.05$	$P > 0.05$

4.1.2 Water temperature

Water temperature at River Kisian averaged 23.9 ± 1.32 °C, with a range of 21.9 °C to 27.7 °C before weir construction (Table 3). The highest temperature was recorded at the upstream (25.9 ± 1.1), followed by downstream (25.1 ± 1.87) and midstream (23.9 ± 1.32). At Awach-seme River, water temperature ranged from low of 22.6°C to a high of 27.8°C, with a mean of 24.8 ± 1.13 °C at the upstream site, 27.1 ± 0.64 °C at the midstream and 26.8 ± 0.65 °C at the downstream site (Table 3).

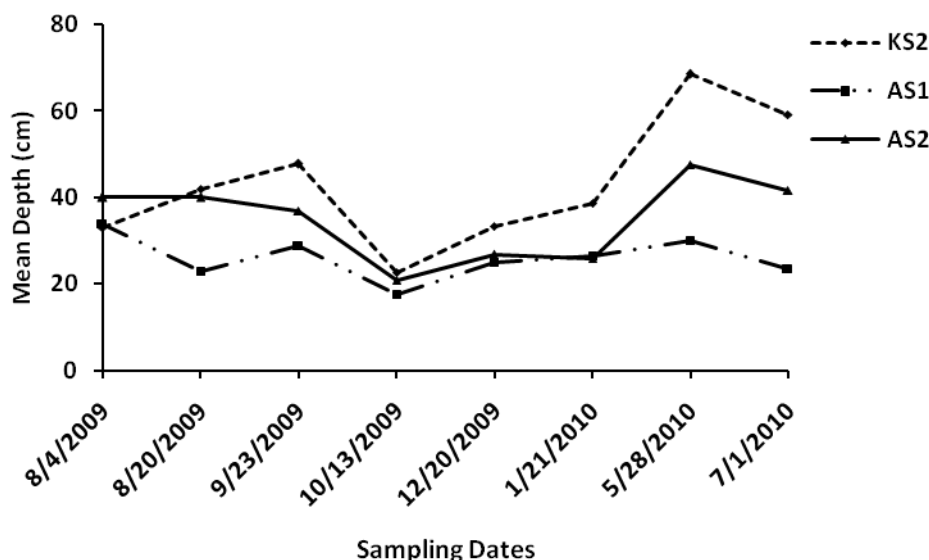


Figure 2. Mean water depth recorded at sites KS2 (Kisian), AS1 and AS2 (Awach-seme) during the study period, August 2009 to July 2010.

Table 3. Mean water temperatures ($^{\circ}\text{C}$) at three sampling sites (upstream, midstream and downstream) along Rivers Kisian and Awach-seme, Lake Victoria Basin, $n=9$.

		Mean water temperature ($^{\circ}\text{C}$)		
		Upstream	Midstream	Downstream
R. Kisian	Mean \pm SE	25.90 \pm 1.10	23.90 \pm 1.32	25.10 \pm 1.87
	Ranges	23.50 – 27.50	21.90 – 27.70	21.60 – 25.70
R. Awach-seme	Mean \pm SE	24.80 \pm 1.13	27.10 \pm 0.64	26.80 \pm 0.65
	Ranges	22.60 – 27.70	25.60 – 27.80	25.20 – 27.5

After weir installation, water temperature at Kisian (KS2) varied from 23.4°C to 25.9°C with a mean of $25.0 \pm 0.59^{\circ}\text{C}$ (Figure 3). At Awach-seme River, average water temperature ranged from 23.2°C to 27.8°C with a mean of 25.4 ± 0.9 and 26.6 ± 0.43 at sites AS1 and AS2 respectively (Table 4). Mean water temperature before and after weir installation at River Awach-seme were equal having $25.9 \pm 0.68^{\circ}\text{C}$ and $25.9 \pm 0.69^{\circ}\text{C}$ respectively.

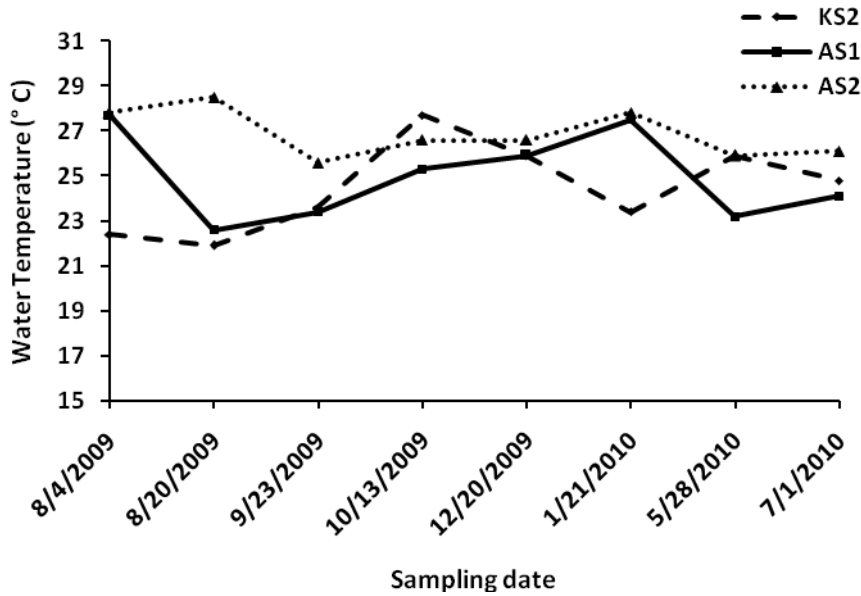


Figure 3. Water temperature (mean \pm SE) at Kisian (KS2) and Awach-seme (AS1 and AS2) Rivers during the study period.

Table 4. Water temperature at River Kisian (KS2) and Awach-seme (AS1 and AS2) after weir construction, n=4.

	Mean water temperature (°C) \pm SE		
	River Kisian KS2	River Awach-seme AS1 AS2	
Before weir	23.90 \pm 1.32	24.80 \pm 1.13	27.10 \pm 0.64
After weir	25.00 \pm 0.59	25.40 \pm 0.90	26.60 \pm 0.43
Significance	P>0.05	P>0.05	P>0.05

4.1.3 Flow rate

River Kisian experienced very low flow rate during the dry season, reaching a low of 0.16 m/s but this increased to a high of 1.30 m/s as the rainy season progressed. Mean flow rate prior to weir installation was 0.42 \pm 0.11m/s. Flow rate among sampling stations did not differ significantly ($F_{2,8} = 0.87$, $P > 0.05$; Table 5). At River Awach-seme, flow rate ranged from 0.31

m/s to 0.91 m/s, (Table 5). Mean flow rates among sampling sites did not differ significantly ($F_{2,9} = 0.55$, $P > 0.05$; Figure 4).

Table 5. Mean flow rate and their ranges at Rivers Kisian and Awach-seme prior to weir installation, n =9.

		Mean Flow rate (m/s)			Anova
		Upstream	Midstream	Downstream	
R. Kisian	Mean \pm SE	0.42 \pm 0.10	0.71 \pm 0.23	0.48 \pm 0.94	0.87 ^{n.s}
	Ranges	0.31 – 0.60	0.16 – 1.30	0.38 – 0.73	
R. Awach-seme	Mean \pm SE	0.68 \pm 0.09	0.55 \pm 0.12	0.71 \pm 0.11	0.55 ^{n.s}
	Ranges	0.41 – 0.80	0.31 – 0.82	0.38 – 0.91	

n.s. non significant

After weir installation, flow rate at site KS2 increased to a high of 0.81 m/s with a mean of 0.59 \pm 0.09 m/s probably because of increased water volume available. However, flow rate at site KS2 did not differ significantly after weir installation ($t = -2.95$; d.f = 3; $p > 0.05$). At Awach-seme River, flow rate ranged from 0.43 m/s to 0.97 m/s with a mean of 0.66 \pm 0.14 m/s and 0.67 \pm 0.12 m/s at AS1 and AS2 respectively (Table 6). Mean flow rate before and after weir installation at sites AS1 and AS2 did not differ significantly ($t = 0.09$; d.f. = 3; $p > 0.05$ at AS1 and $t = -0.73$; d.f. = 3; $p > 0.05$ at AS2). Similarly mean flow rate between the two Rivers did not differ significantly ($t = 0.10$, d.f = 7; $P > 0.05$; Figure 5).

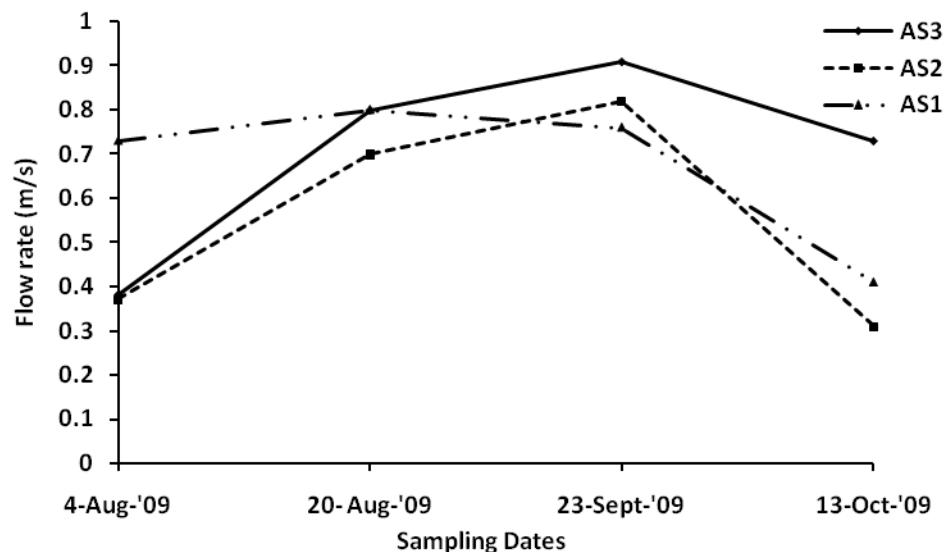


Figure 4. Flow rate recorded at sites AS1, AS2 and AS3 in River Awach-seme before weir installation

Table 6. Mean flow rate at Rivers Kisian (KS2) and Awach-seme (AS1 and AS2) before and after weir installation, n=9.

	Mean flow rate (m/s) \pm SE		
	River Kisian KS2	River Awach-seme AS1 AS2	
Before weir	0.59 \pm 0.09	0.68 \pm 0.09	0.55 \pm 0.12
After weir	0.71 \pm 0.04	0.66 \pm 0.14	0.67 \pm 0.12
Significance	P>0.05	P>0.05	P>0.05

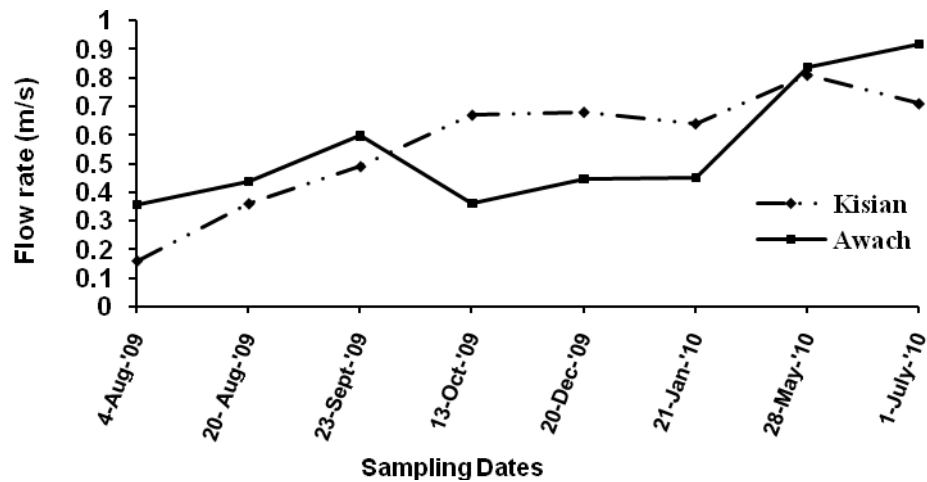


Figure 5. Flow rate (mean \pm SE) recorded at Kisian and Awach Rivers.

4.1.4 Dissolved oxygen

Dissolved oxygen at Kisian River ranged from a minimum of 6.1 mg/l to a maximum of 8.4 mg/l at all sampling sites. The mean D.O. prior to weir installation differed significantly among sites ($F_{2,8} = 6.18, P < 0.05$; Table 7). Post hoc test indicated significant differences between sites KS2 and KS3 and sites KS1 and KS3 (Turkey test, $\alpha = 0.05$). At River Awach-seme, dissolve oxygen varied from 6.9 mg/l to 8.0 mg/l. Mean D.O. did not differ significantly among sites at Awach-seme ($F_{2,9} = 3.02, P > 0.05$; Table 7).

Table 7. Mean dissolved oxygen (mg/l) and their ranges at three sampling sites along Rivers Kisian and Awach-seme prior to weir installation, n=9.

		Mean Dissolved Oxygen (mg/l)			Anova
		Upstream	Midstream	Downstream	
R. Kisian	Mean \pm SE	6.50 \pm 0.25	7.60 \pm 0.28	6.70 \pm 0.15	6.18*
	Ranges	6.10- 7.20	7.20 – 8.40	6.40 – 6.90	
R. Awach-seme	Mean \pm SE	7.70 \pm 0.13	7.20 \pm 0.22	7.30 \pm 0.12	3.02 ^{n.s}
	Ranges	7.40 - 8.00	6.90 – 7.80	7.10 – 7.60	

* Significant at $P > 0.05$

N.s Non significant

On installing the weirs, D.O. at Kisian site KS2 ranged from 7.2 mg/l to 8.6 mg/l with a mean of 7.7 ± 0.31 mg/l (Table 8). Assessment of changes in D.O. before and after weir installation showed no significant increase ($t = 0.45$; d.f. = 3; $P > 0.05$). At sites AS1 and AS2, D.O. after weir installation ranged from 6.2 mg/l to 8.22 mg/l with means of 6.9 ± 0.38 and 7.8 ± 0.15 respectively. Dissolved oxygen did not differ significantly after weir installation at site AS1 ($t = 2.13$; d.f. = 3; $p > 0.05$) but the variation increased significantly at site AS2 ($t = -6.37$; d.f. = 3; $p < 0.05$; Table 8). D.O. between Rivers Awach-seme and Kisian did not differ significantly either, $t = 0.928$; d.f. = 7 $P > 0.05$ (Figure 6).

Table 8. Mean dissolved oxygen at Rivers Kisian (KS2) and Awach-seme (AS1 and AS2) after weir installation, n=4.

	Mean dissolved oxygen (mg/l) \pm SE		
	River Kisian	River Awach-seme	
	KS2	AS1	AS2
Before weir	7.6 \pm 0.28	7.7 \pm 0.13	7.2 \pm 0.22
After weir	7.7 \pm 0.31	6.9 \pm 0.38	7.8 \pm 0.15
Significance	$P > 0.05$	$P > 0.05$	$P < 0.05$

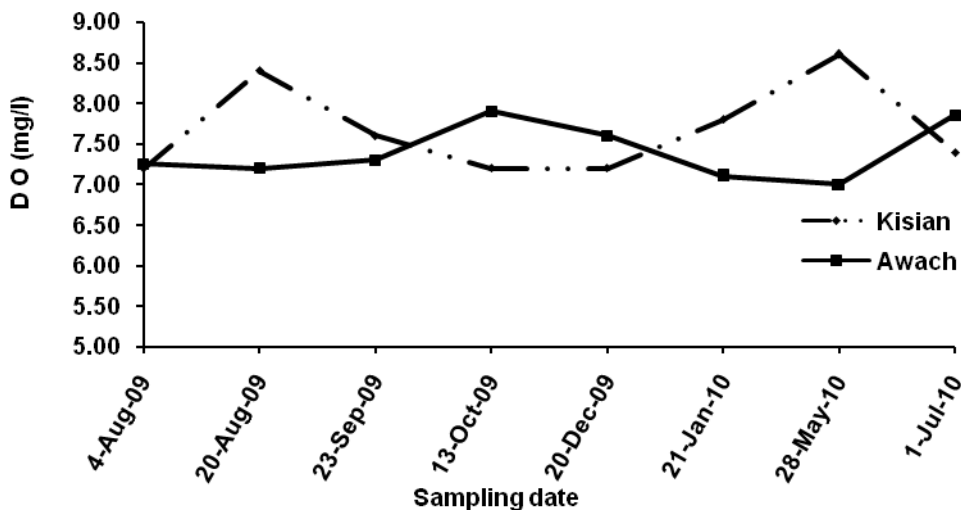


Figure 6. Mean dissolve oxygen at Kisian and Awach-seme Rivers during the study period.

4.1.5 Conductivity

Conductivity at River Kisian varied from a low 40 $\mu\text{s}/\text{cm}$ to a high of 175 $\mu\text{s}/\text{cm}$ averaging 89.6 ± 24.44 during pre-weir period. Mean Conductivity did not differ significantly among the three sampling sites ($F_{2,8} = 0.12, P > 0.05$; Table 9). At Awach-seme River conductivity varied from 110 to 220 $\mu\text{s}/\text{cm}$. Mean water conductivity prior to weir installation did not differ significantly among sites AS1, AS2 and AS3 ($F_{2,9} = 0.33, P > 0.05$; Table 9).

Table 9. Mean conductivity ($\mu\text{s}/\text{cm}$) and their ranges at Rivers Kisian and Awach-seme prior to weir installation, n=9.

		<u>Mean conductivity ($\mu\text{S}/\text{cm}$)</u>			
		Upstream	Midstream	Downstream	Anova
R. Kisian	Mean \pm SE	97.50 \pm 26.19	89.60 \pm 24.44	79.80 \pm 27.27	0.12 ^{n.s}
	Ranges	60.55–175.00	40.00–156.00	90.00–119.00	
R. Awach-seme	Mean \pm SE	155.80 \pm 24.25	180.80 \pm 20.79	175.00 \pm 23.30	0.33 ^{n.s}
	Ranges	110.00–210.00	140.00–220.00	110.00–220.00	

During the post weir period, conductivity at site KS2 ranged from 47 to 82 $\mu\text{s}/\text{cm}$ with a mean of $65.7 \pm 8.67\mu\text{s}/\text{cm}$. Conductivity did not differ significantly between pre and post-weir periods at KS2 ($t = 0.78$; d.f =3; $P > 0.05$). At River Awach-seme, conductivity ranged from a low of 93.6 $\mu\text{s}/\text{cm}$ to a high of 193 $\mu\text{s}/\text{cm}$, with a mean of $120.2\pm 14.65\mu\text{s}/\text{cm}$ and $133.9\pm 22.21\mu\text{s}/\text{cm}$ at sites AS1 and AS2 respectively. Conductivity at sites AS1 and AS2 did not differ significantly after weir installation ($t = 1.15$; d.f. = 3; $p > 0.05$ at AS1 and $t = 1.46$; d.f. = 3; $p > 0.05$ at AS2; Table 10). A significant difference in conductivity was observed between the two rivers during the study period ($t = -5.85$; d.f =7; $P = 0.001$; Figure 7).

Table 10. Conductivity at Rivers Kisian (KS2) and Awach-seme (AS1 and AS2) before after weir installation, n=4.

	Mean conductivity ($\mu\text{S}/\text{cm}$) \pm SE		
	River Kisian	River Awach-seme	
	KS2	AS1	AS2
Before weir	89.6 \pm 24.44	155.8 \pm 24.25	180.8 \pm 20.79
After weir	65.7 \pm 8.67	120.2 \pm 14.65	133.9 \pm 22.21
Significance	P>0.05	P>0.05	P>0.05

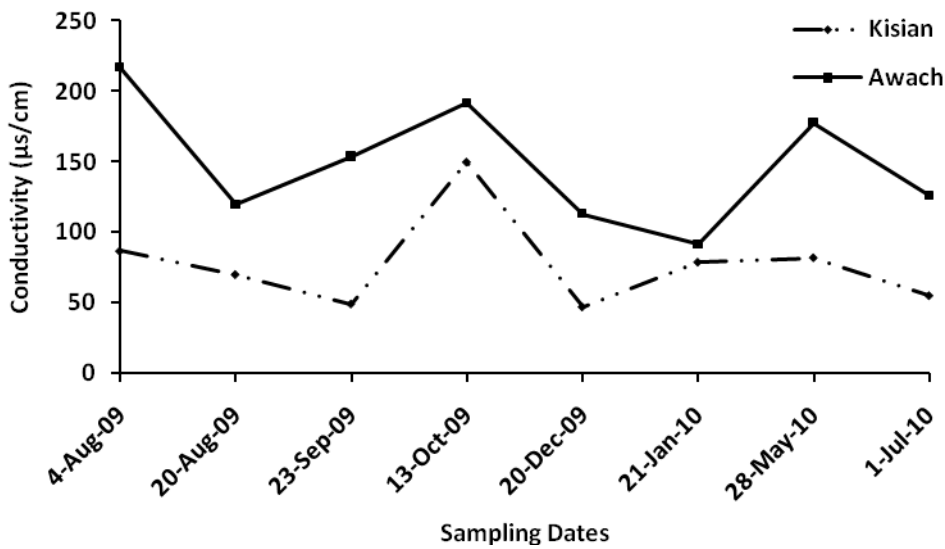


Figure 7. Mean conductivity at Rivers Kisian and Awach-seme during the study period.

4.1.6 Water pH

Water pH at River Kisian ranged from 6.7 to 7.7 with a mean of 7.2 ± 0.19 before weir installation. Mean water pH prior to weir installation did not differ significantly among sites ($F_{2,8} = 0.75$, $P > 0.05$; Table 11). At River Awach-seme, water pH ranged from 7.6 to 8.4 prior to weir installation. Mean water pH did not differ significantly among sites AS1, AS2 and AS3 ($F_{2,9} = 0.37$, $p > 0.05$; Table 11).

Table 11. Mean water pH and their ranges at Rivers Kisian and Awach-sume before weir installation, n=9.

		Mean water pH \pm			Anova
		Upstream	Midstream	Downstream	
R. Kisian	Mean \pm SE	7.00 \pm 0.11	7.20 \pm 0.19	7.20 \pm 0.23	0.75 ^{n.s}
	Ranges	6.72 – 7.26	6.72 – 7.52	6.95 – 7.68	
R. Awach-sume	Mean \pm SE	7.80 \pm 0.24	8.00 \pm 0.07	7.80 \pm 0.24	0.37 ^{n.s}
	Ranges	7.24 – 8.40	7.92 – 8.22	7.17 – 8.33	

n.s. Non significant

After weir installation, pH at Kisian (KS2) ranged from 7.1 to 8.0 having a mean 7.5 ± 0.21 . Water pH at site KS2 showed no significant difference between pre and post-weir periods ($t = -1.64$; d.f = 3; $P > 0.05$; Table 12). pH at Awach-sume River varied from 7.1 to 8.3 having a mean of 7.5 ± 0.21 at AS1 and 7.6 ± 0.25 at AS2. Mean water pH did not differ significantly at sites AS1 and AS2 after weir installation ($t = 0.79$; d.f = 3; $p > 0.05$ and $t = 1.50$; d.f = 3; $p > 0.05$ respectively; Table 12.). Water pH did not differ significantly between the two rivers $t = -1.784$; d.f = 7; $P > 0.05$ (Figure 8).

Table 12. Water pH before and after weir installation at River Kisian (KS2) and Awach-sume (AS1 and AS2), n=4.

	Mean water pH \pm SE		
	River Kisian	River Awach-sume	
	KS2	AS1	AS2
Before weir	7.20 \pm 0.19	7.80 \pm 0.24	8.00 \pm 0.07
After weir	7.50 \pm 0.21	7.50 \pm 0.21	7.60 \pm 0.25
Significance	$P > 0.05$	$P > 0.05$	$P > 0.05$

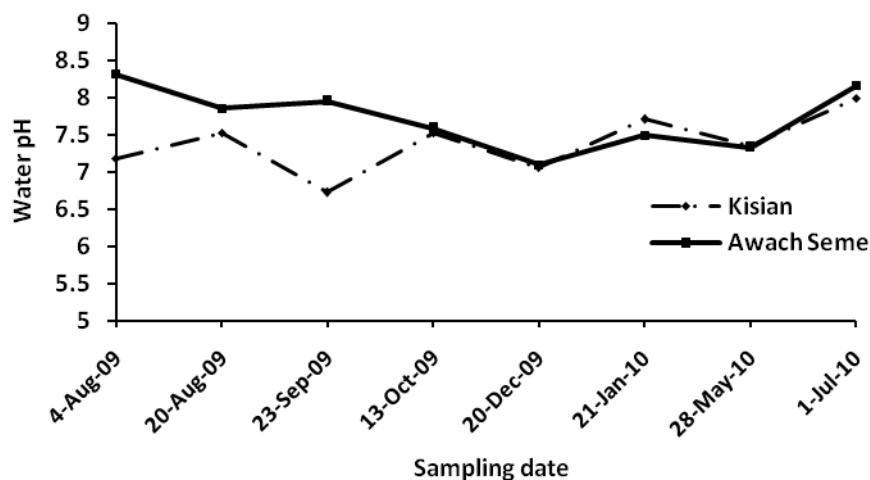


Figure 8. Mean water pH at Kisian and Awach-seme Rivers during the study period.

4.2 Nutrients

4.2.1 Nitrates

Nitrates at River Kisian ranged from 363.1 to 368.2 $\mu\text{gN/l}$ before weir installation (Table 13). There was a significant difference in nitrates among sites KS1, KS2 and KS3 before weir installation ($F_{2,9} = 35.80$, $P < 0.05$; Figure 9). Post hoc analysis indicated significant differences between site KS2 and site KS3, site KS1 and site KS3 and site KS1 and site KS2 (Turkey test, $\alpha = 0.05$). At River Awach-seme, nitrates ranged from a low of 99.6 to a high of 322.4 $\mu\text{gN/l}$ prior to weir installation (Table 13). There was no significant difference in nitrates among sites AS1, AS2 and AS3 ($F_{2,9} = 0.52$, $P > 0.05$; Figure 10).

Table 13. Mean nitrate concentrations and their ranges at Rivers Kisian and Awach-seme prior to weir construction, n=9.

		Mean nitrate concentration ($\mu\text{gN/l}$)			Anova
		Upstream	Midstream	Downstream	
R. Kisian	Mean \pm SE	438.40 \pm 13.50	364.70 \pm 1.16	308.40 \pm 13.07	35.80*
	Ranges	408.50–461.30	363.10–368.20	276.60–331.00	
R. Awach-seme	Mean \pm SE	249.20 \pm 63.03	170.90 \pm 45.67	239.10 \pm 66.28	0.52 ^{n.s}
	Ranges	102.70–372.70	90.70–272.10	64.70–372.10	

* Significant

N.s. Non significant

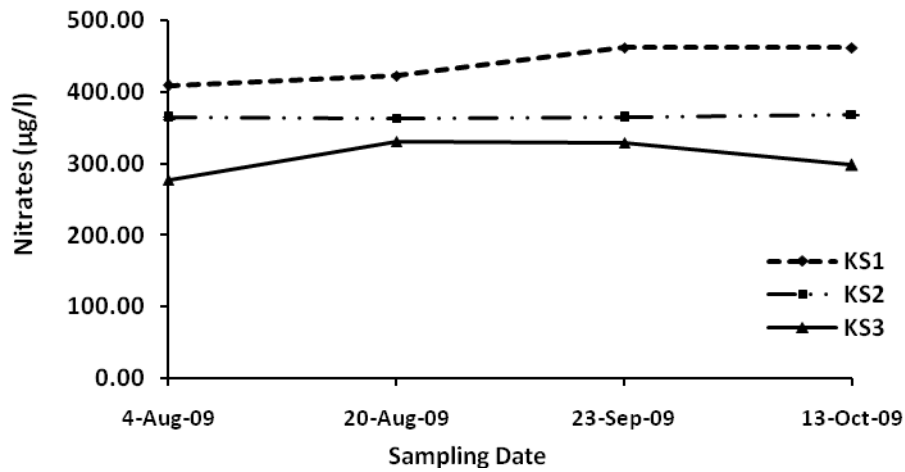


Figure 9. Nitrate concentration among sites at River Kisian during the pre-weir period

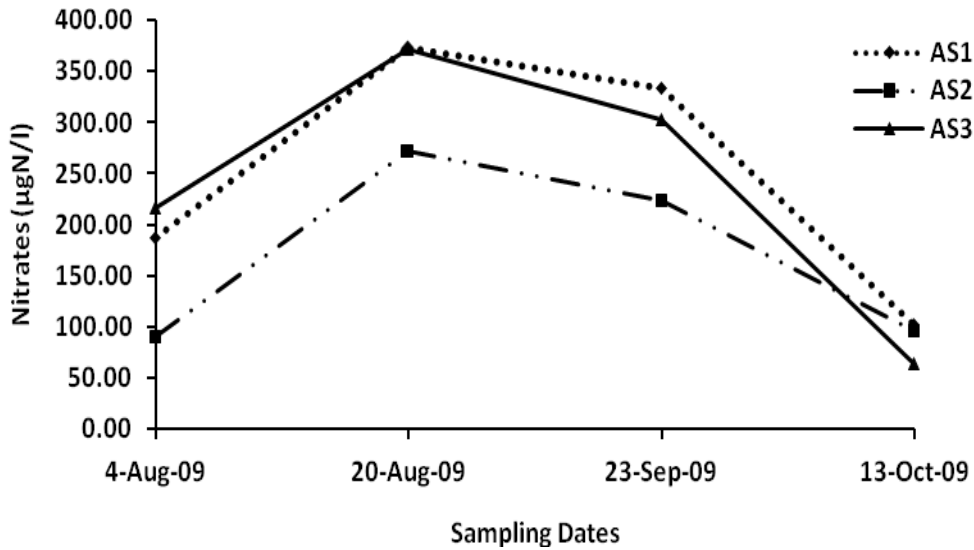


Figure 10. Nitrate concentration at Awach-seme River (AS1, AS2 and AS3) before weir installation

After weir installation, nitrate concentration at River Kisian (KS2) dropped to a low of 30.1 and a high of 59.9µgN/l with a mean of $38.1 \pm 7.27\mu\text{gN/l}$. River Kisian had a significant difference in nitrates after weir installation $t = 33.01$, $P < 0.05$ (Figure 11). Whereas at River Awach-seme, nitrate concentration ranged from a low of 46.9µgN/l to a high of 110.9µgN/l after weir installation. Nitrate concentration at sites AS1 and AS2 did not differ significantly after weir installation ($t = 2.56$; d.f. =3; $p > 0.05$ and $t = 1.79$; d.f.=3; $p > 0.05$, respectively) indicating a non significant decrease in nitrate concentrations (Table 14). Nitrate concentrations between the two Rivers did not differ significantly either ($t = 1.38$; d.f = 7; $P > 0.05$; Figure 12).

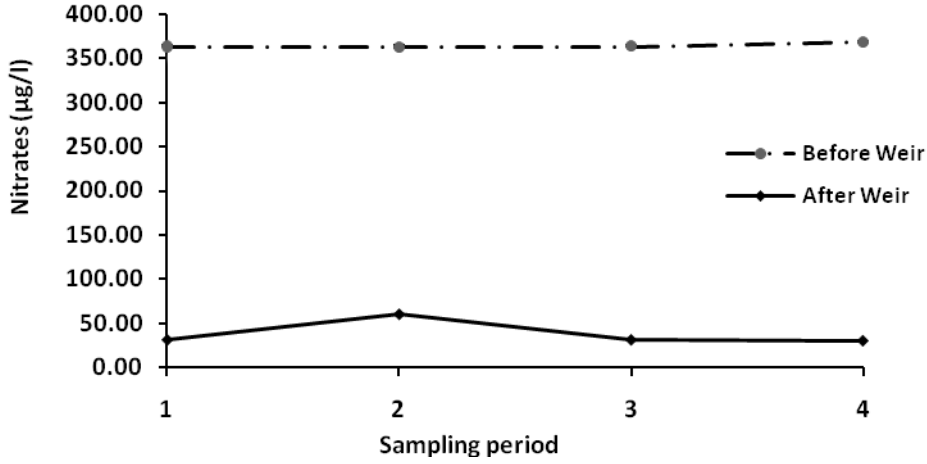


Figure 11. Nitrate concentration at River Kisian during the Pre-weir and Post-weir periods.

Table 14. Nitrate concentrations ($\mu\text{gN/l}$) before and after weir installation at Rivers Kisian (KS2) and Awach-seme (AS1 and AS2), $n=4$.

	Mean nitrate concentration ($\mu\text{gN/l}$) \pm SE		
	<u>River Kisian</u>	<u>River Awach-seme</u>	
	KS2	AS1	AS2
Before weir	364.70 \pm 1.16	249.20 \pm 63.03	170.90 \pm 45.67
After weir	38.10 \pm 7.27	73.80 \pm 13.70	66.80 \pm 15.02
Significance	P<0.05	P>0.05	P>0.05

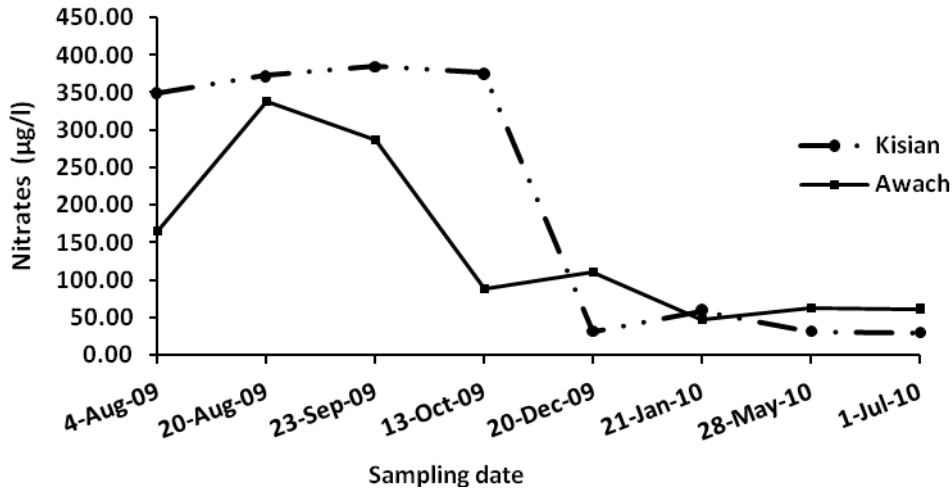


Figure 12. Nitrate concentration between Kisian and Awach-seme Rivers during the study period, August 2009 to July 2010.

4.2.2 Soluble reactive phosphates

Soluble Reactive Phosphates (SRP) at Kisian River ranged from 9.7 to 77.0µgP/l with a mean of $27.2 \pm 8.4\mu\text{gP/l}$ before weir installation (Table 15). SRP did not differ significantly among sites KS1, KS2 and KS3 ($F_{2,9} = 0.03$, $P > 0.05$; Figure 13). At River Awach-seme, SRP varied from 15.7 to 46.0µgP/l before weir installation. Mean SRP concentration did not differ significantly among sites ($F_{2,9} = 0.64$, $P > 0.05$; Table 15).

Table 15. Mean Soluble reactive phosphate concentrations (µgP/l) and their ranges at Rivers Kisian and Awach-seme prior to weir installation, n=9.

		Mean SRP concentration (µgP/l)			Anova
		Upstream	Midstream	Downstream	
R. Kisian	Mean ± SE	30.90±15.44	27.20±8.40	28.5±9.95	0.03 ^{n.s}
	Ranges	11.00–76.95	9.66–50.03	15.04–58.11	
R. Awach-seme	Mean ± SE	22.10±4.89	26.50±7.17	31.5±5.42	0.64 ^{n.s}
	Ranges	15.04–36.57	15.04–45.99	16.36–41.96	

N.s. Non significant

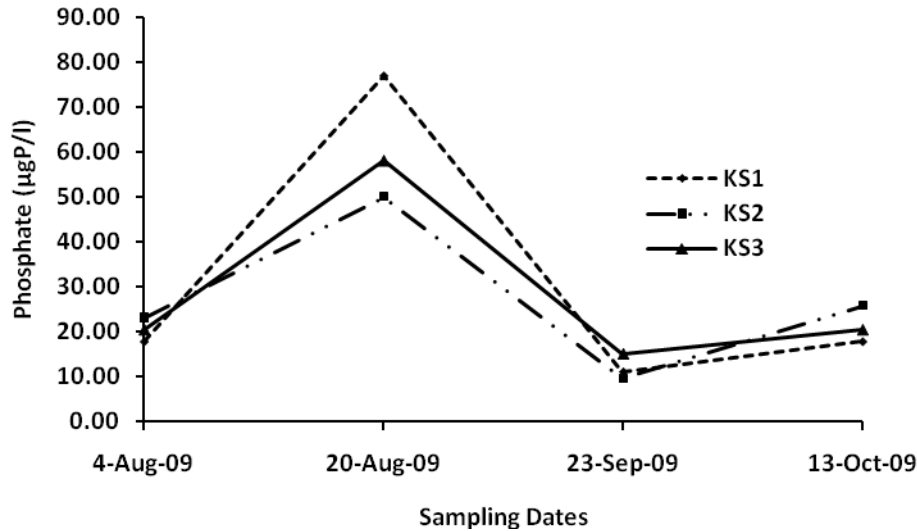


Figure 13. Phosphate concentrations at Kisian River before weir installation

On installing the weirs, SRP concentrations at Kisian River (KS2) escalated to values between 37.6 and 58.0µgP/l with a mean of $48.6 \pm 5.28\mu\text{gP/l}$ (Table 16). Concentrations of SRP did not differ significantly after weir installation at site KS2 ($t = -1.67$; $d.f = 3$; $p > 0.05$). Soluble reactive phosphates at River Awach-seme after weir installation ranged from 15.2 to 72.1µgP/l, with means of $39.6 \pm 7.36\mu\text{gP/l}$ at site AS1 and $42.4 \pm 16.85\mu\text{gP/l}$ at site AS2. Mean SRP did not differ significantly after weir installation at sites AS1 and AS2 ($t = -1.46$; $d.f. = 3$; $p > 0.05$ at AS1 and $t = -0.75$; $d.f. = 3$; $p > 0.05$ at AS2; Table 16). Comparisons of SRP concentrations between the two rivers showed no significant difference either, ($t = 0.72$; $d.f = 7$; $P > 0.05$; Figure 14).

Table 16. Soluble Reactive Phosphate concentrations ($\mu\text{gP/l}$) before and after weir installation at River Kisian (KS2) and Awach-sume (AS1 and AS2), $n=4$.

	Mean SRP concentration ($\mu\text{gP/l}$) \pm SE		
	River Kisian	River Awach-sume	
	KS2	AS1	AS2
Before weir	27.20 \pm 8.40	22.10 \pm 4.89	26.50 \pm 7.17
After weir	48.60 \pm 5.28	39.60 \pm 7.36	42.40 \pm 16.85
Significance	P>0.05	P>0.05	P>0.05

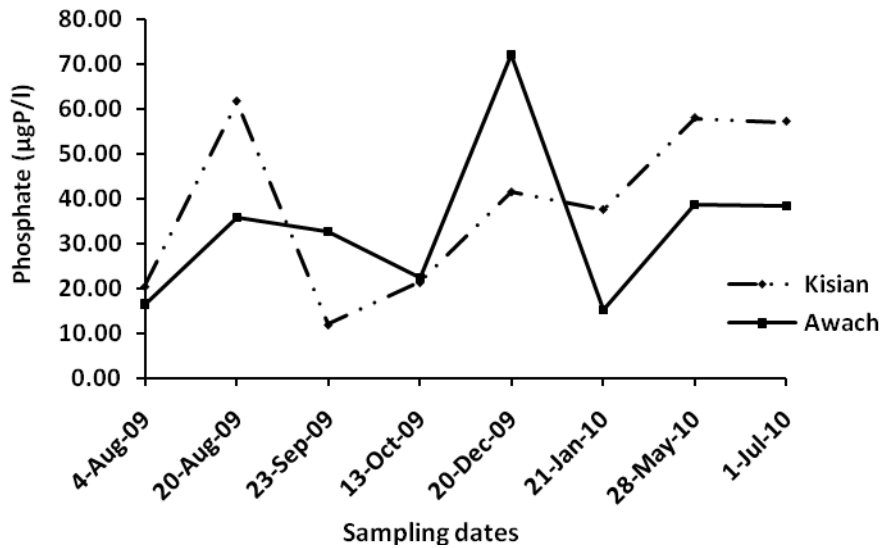


Figure 14. Phosphate concentration between Kisian and Awach-sume Rivers during the study period.

4.2.3 Silicates

Silicates at River Kisian varied from 21.2 to 38.7 mg/l prior to weir installation, (Table 17). Mean Silicate concentration among the sites at Kisian River, during the pre-weir period did not vary significantly ($F_{2,9} = 0.09$, $P > 0.05$). At River Awach-seme, silicates ranged from a low of 19.0 to a high of 31.2mg/l before weir installation. Mean silicate concentration did not differ significantly among sites before weir installation at Awach-seme River ($F_{2,9} = 0.65$, $P > 0.05$; Table 17).

Table 17. Mean silicate concentration (mg/l) and their ranges at Rivers Kisian and Awach-seme during the pre-weir period, n=9.

		<u>Mean Silicate concentration (mg/l)</u>			
		Upstream	Midstream	Downstream	Anova
R. Kisian	Mean ± SE	29.70±3.06	28.00±3.35	29.60±3.40	0.09 ^{n.s}
	Ranges	21.17–35.27	21.49–34.95	22.58–38.71	
R. Awach-seme	Mean ± SE	23.80±1.72	26.20±1.73	27.10±2.71	0.65 ^{n.s}
	Ranges	18.98–26.81	21.49–29.63	19.45–31.19	

N.s Non significant

After weir installation, silicates at River Kisian (KS2) rose to values between 27.4 and 79.3mg/l having a mean of 56.5 ± 13.37 mg/l. Silicate concentration did not differ significantly after weir installation at KS2 ($t = -1.84$; d.f = 3; $P > 0.05$; Table 18). Silicate concentration at Awach-seme River ranged from 27.8 to 78.9mg/l, with a mean of 39.6 ± 7.36 mg/l at AS1 and 42.4 ± 16.85 mg/l at AS2. There was no significant difference in silicates after weir installation at sites AS1 and AS2 ($t = -2.1$; d.f. =3; $p > 0.05$ and $t = -1.9$; d.f. =3; $p > 0.05$ respectively, Table 18). Silicates concentration between the two rivers differed significantly during the pre-weir periods ($t = 3.31$; d.f = 3; $P < 0.05$) but the variation was insignificant during the post weir period ($t = 0.88$; d.f = 3; $P > 0.05$; Figure 14). It was apparent that as the levels of nitrates dwindled (Figure 12), those of silicates increased (Figure 15) while phosphates were indistinct (Figure 14).

Table 18. Mean silicates (mg/l) before and after weir installation at Kisian (KS2) and Awach-
 seme (AS1 and AS2), n=4.

	Mean Silicate concentration (mg/l) \pm SE		
	River Kisian	River Awach-seme	
	KS2	AS1	AS2
Before weir	28.00 \pm 3.35	23.80 \pm 1.72	26.20 \pm 1.73
After weir	56.50 \pm 13.37	53.50 \pm 13.23	53.40 \pm 13.20
Significance	P>0.05	P>0.05	P>0.05

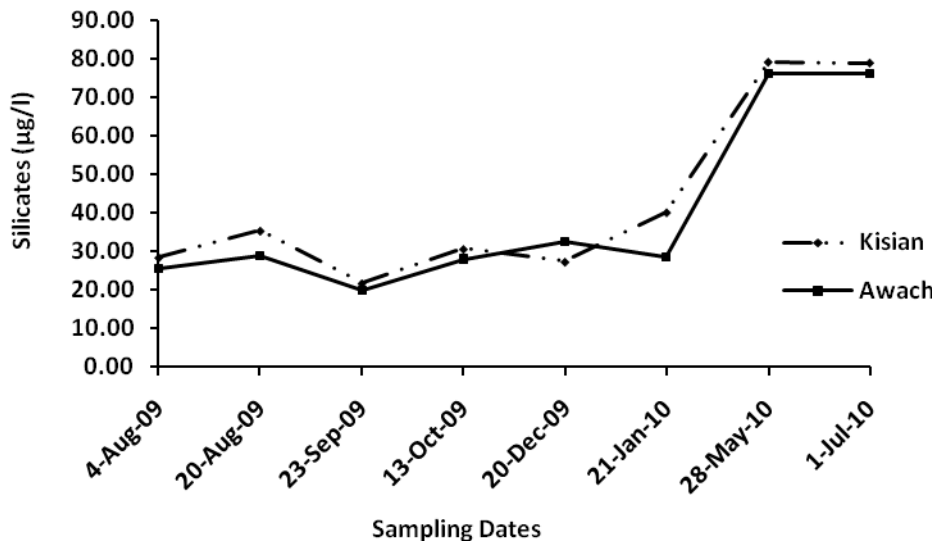


Figure 15. Silicate concentrations between river Kisian and Awach-seme during the sampling period.

4.2.4 Turbidity

Turbidity at River Kisian during the pre-weir period ranged from minimum of 86 to a maximum of 1500NTU's (Table 19). Turbidity was significantly different among sites at Kisian River during the pre-weir period ($F_{2,8} = 6.73$, $P < 0.05$). Turkey test indicated significant differences between site KS2 and KS3 and KS1 and KS2 ($\alpha = 0.05$). At River Awach-seme, turbidity ranged from a low of 38 to a high of 1380NTU's during the pre-weir period. Mean turbidity was not

significantly different among sites at River Awach-seme before weir installation ($F_{2,9} = 0.21$, $P > 0.05$; Table 19).

Table 19. Mean turbidity (NTU's) and their ranges at Kisian and Awach-seme Rivers before weir installation, n=9.

		Mean Turbidity (NTU's)			Anova
		Upstream	Midstream	Downstream	
R. Kisian	Mean \pm SE	333.00 \pm 128.30	774.50 \pm 280.89	1410.00 \pm 80.21	6.73*
	Ranges	86.00-5560.00	583.00-1426	250.00-1500.00	
R. Awach-seme	Mean \pm SE	576.80 \pm 290.27	371.50 \pm 147.88	557.80 \pm 277.70	0.21 ^{n.s}
	Ranges	38.00-1380.00	50.00-660.00	65.00-1180.00	

* Significant

N.s. Non significant

After weir installation, turbidity at River Kisian (KS2) declined to values between 76.1 and 117.6NTU's with a mean of 100.9 ± 9.24 NTU's. Mean turbidity differed significantly after weir installation at KS2 ($t = 4.25$; d.f = 3; $P < 0.05$; Figure 16). At River Awach-seme, turbidity ranged from 46.1 to 194NTU's with means of 142.3 ± 19.07 NTU's and 105 ± 28.24 NTU's at sites AS1 and AS2 respectively. Turbidity did not differ significantly after weir installation at site AS1 ($t = 1.43$; d.f. =3; $p > 0.05$) and site AS2 ($t = 1.61$; d.f. = 3; $p > 0.05$). Unlike Kisian, River Awach-seme did not show a significant difference in turbidity after weir installation ($t = 1.52$; d.f = 3; $P > 0.05$; Table 20). Turbidity between the two rivers was not significantly different ($t = 1.15$; d.f = 7; $P > 0.05$; Figure 17).

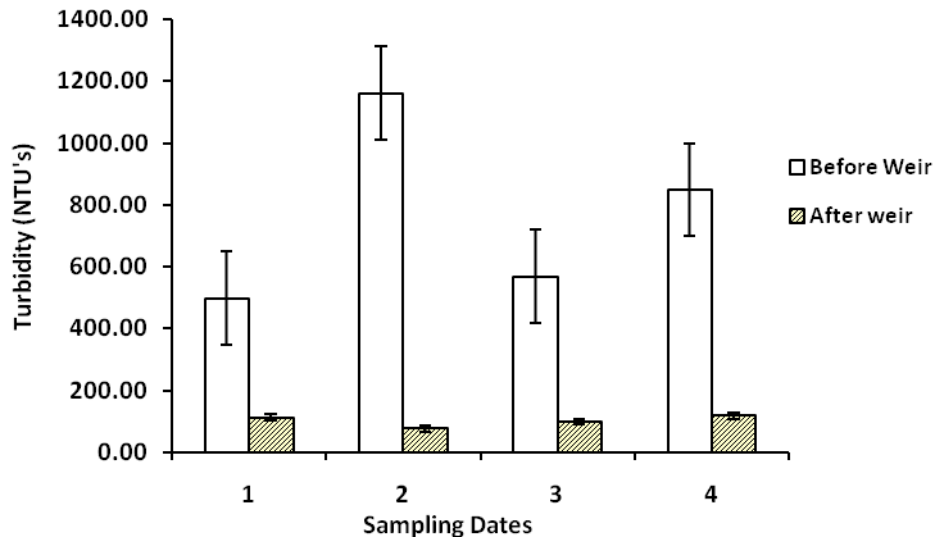


Figure 16. Turbidity at River Kisian (KS2) before and after weir installation

Table 20. Turbidity (NTU's) before and after weir construction at Kisian (KS2) and Awach-seme (AS1 and AS2) Rivers, n=4.

	Mean Turbidity (NTU's) \pm SE		
	River Kisian KS2	River Awach-seme AS1 AS2	
Before weir	774.50 \pm 280.89	576.80 \pm 290.27	371.50 \pm 147.9
After weir	101.00 \pm 9.24	142.30 \pm 19.07	105.00 \pm 28.24
Significance	P<0.05	P>0.05	P>0.05

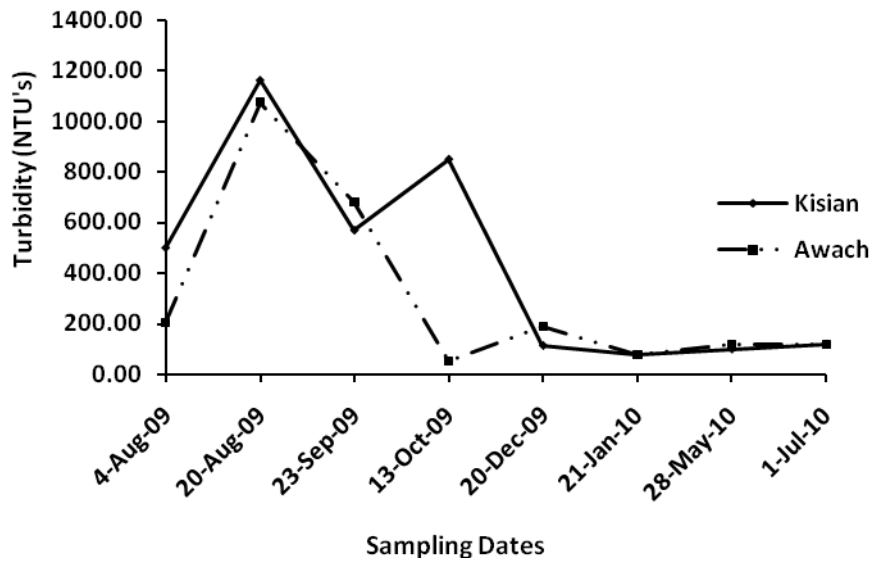


Figure 17. Turbidity between River Kisian and Awach-seme during the the sampling period, August 2009 to July 2010.

4.2.5 Total dissolved solids

Total Dissolved Solids (TDS) at Kisian River ranged from 11 to 210mg/l prior to weir placement. Mean TDS did not differ significantly among sites ($F_{2,8} = 1.06, P > 0.05$), before weir installation (Table 21). Total dissolved solids at River Awach-seme ranged from 40 to 220mg/l before weir placement. Mean turbidity did not differ significantly among sites AS1, AS2 and AS3 ($F_{2,9} = 0.1, P > 0.05$; Table 21).

Table 21. Mean TDS (mg/l) and their ranges at Rivers Kisian and Awach-sume prior to weir installation, n=9.

		Mean TDS (mg/l)			Anova
		Upstream	Midstream	Downstream	
R. Kisian	Mean ± SE	50.00±20.14	50.00±21.21	106.70±51.77	1.06 ^{n.s}
	Ranges	11.00-40.00	11.00- 50.00	50.00–210.00	
R. Awach-sume	Mean ± SE	110.00±40.41	97.50±13.15	95.00±13.23	0.1 ^{n.s}
	Ranges	40.00-220.00	70.00–120.00	60.00–120.00	

N.s Non significant

During the post weir period, TDS at River Kisian (KS2) ranged from 136 to 674mg/l with a mean of 302 ± 124.9 mg/l. There was no significant variation in TDS after weir installation at site KS2 ($t = -2.06$; d.f = 3; $P > 0.05$). At River Awach-sume, TDS ranged from 140 to 2578mg/l with a mean of 282.8 ± 133.21 mg/l at site AS1 and 772.3 ± 601.94 mg/l at site AS2. There was no significant variation in TDS after weir installation at sites AS1 ($t = -1.26$; d.f = 3; $P > 0.05$) and AS2 ($t = -1.14$; d.f. =3; $p > 0.05$; Table 22). Either, TDS was not significantly different between the two Rivers ($t = -1.2$; d.f = 7; $P > 0.05$; Figure 18).

Table 22. Mean TDS before and after weir installation at River Kisian (KS2) and Awach-sume (AS1 and AS2), n=4.

	Mean TDS(mg/l) ± SE		
	River Kisian	River Awach-sume	
	KS2	AS1	AS2
Before weir	50.00±21.21	110.00±40.41	97.50±13.15
After weir	302.00±124.89	282.80±133.21	772.30±601.94
Significance	P>0.05	P>0.05	P>0.05

N.S. Not significant

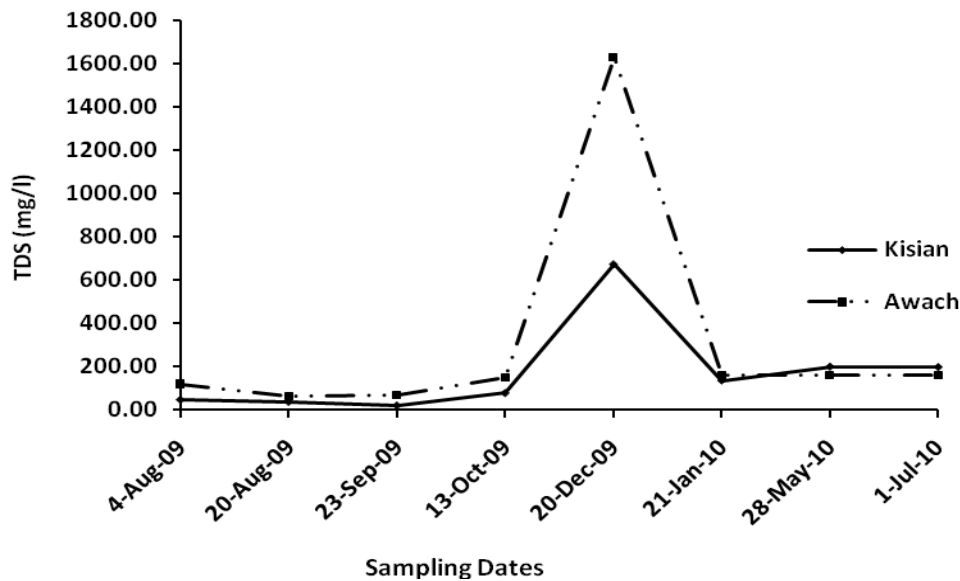


Figure 18. Total dissolved solids at Kisian and Awach-seme rivers during the study period.

4.3 Bottom substratum

Bottom substratum at the Kisian River upstream site (KS1) was largely composed of sand and silt, covering over 80% of the substratum (Figure 19). The rest was mainly gravel. At the mid-stream (KS2), boulders and cobbles covered over 70% of the bottom substratum prior to weir construction, with rest consisting of gravel, sand, and silt in almost equal proportions. Bottom substratum at the downstream site (KS3) was similar to the upstream site consisting largely of sand and silt, mixed with small proportions of gravel. At River Awach-seme, the bottom substratum prior to weir construction was largely composed of gravel at both upstream (AS1) and downstream sites (AS3), constituting over 30% of the bottom constituents (Figure 19). The rest was mainly sand, silt, cobbles and boulders. At the midstream (AS2), the bottom substratum was mainly composed of sand and gravel constituting over 60%. The rest was mainly boulders and cobbles mixed with silt.

Weir installation did not affect the bottom substratum at the mid-stream site of River Kisian with boulders and cobbles continuing to dominate (Figure 20). In contrast, the bottom substrate type at River Awach-seme, changed markedly after weir construction with gravel being replaced by boulders and cobbles at both the upstream (AS1) and mid-stream (AS2) sites. Similarly, silt also

increased at both sites constituting over 11% and 30 %, at AS1 and AS2, respectively (Figure 20).

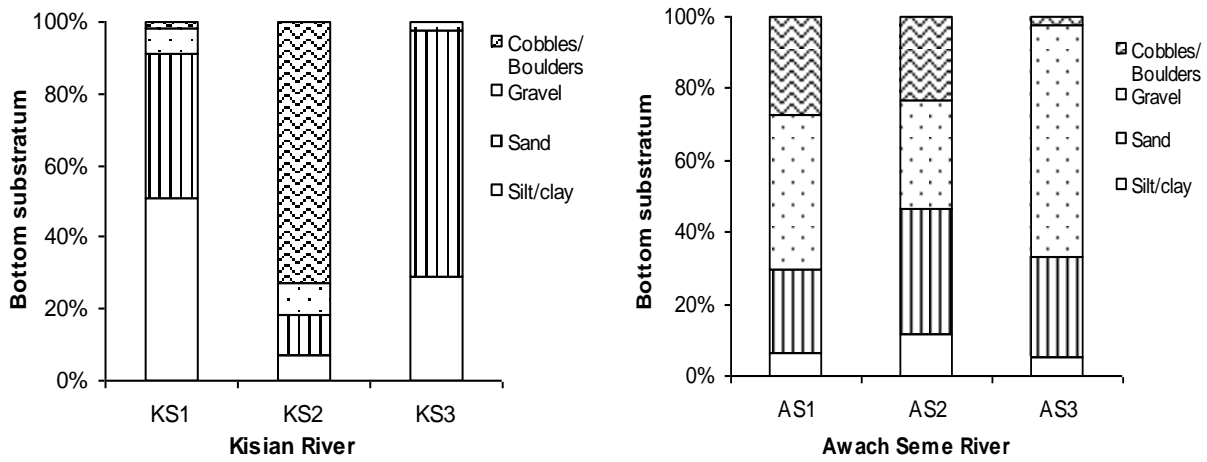


Figure 19. Bottom substratum of Kisian and Awach-seme Rivers prior to weir construction.

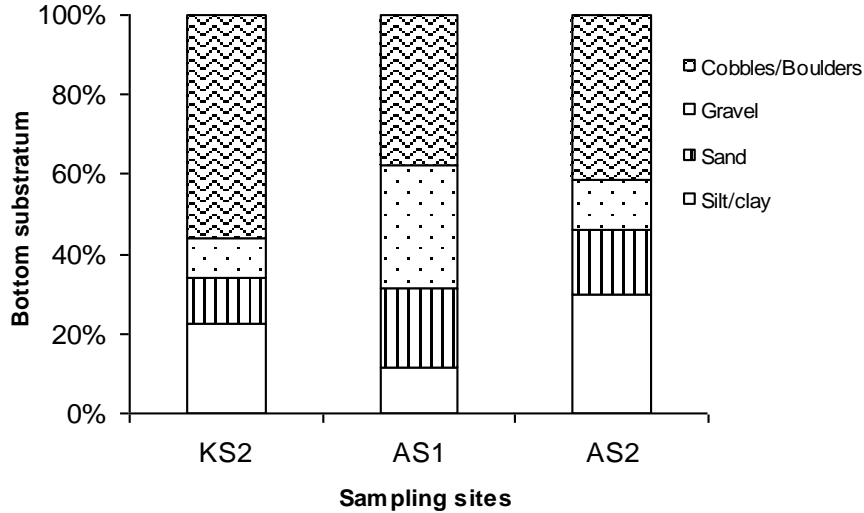


Figure 20. Bottom substratum of Kisian (KS2) and Awach-seme (AS1 and AS2) Rivers after weir construction.

4.4 Macroinvertebrate communities

4.4.1 Composition and density of benthic macroinvertebrates

In total 7157 macroinvertebrate individuals belonging to 31 genera were counted at all sampling sites. The order Ephemeroptera was the most diverse in both rivers having seven genera. Orders Plecoptera, Megaloptera, Hemiptera and Lepidoptera were the least diverse contributing less than 2%. In both Rivers, Chironomidae was the most abundant taxa followed by *Baetis* sp. (Table 23). There was no significant difference in macroinvertebrate density between the two Rivers before weir installation ($t = -2.8$; $d.f = 3$; $p > 0.05$) however, it was significantly different after weir construction ($t = -7.63$; $d.f = 3$; $p < 0.05$).

A total of 23 genera were obtained at River Kisian before weir construction (Table 23). Chironomidae larvae dominated the community with 63% whereas Ephemeroptera (*Baetis* sp. and *Afronurus* sp.) and Trichoptera (*Hydropsyche* sp.) contributed 12.8, 4.9 and 9.5%, respectively. Other groups constituted 12%. At River Awach-sume, 26 genera were obtained before weir installation. Chironomidae and Simuliidae were the dominant taxa, contributing 62.6% of the total macroinvertebrates, with Ephemeroptera (*Baetis* sp., *Caenis* and *Afronurus* sp.), Trichoptera (*Hydropsyche* sp.) and Nematoda constituting 16.5, 9.3 and 2.1%, respectively. Other groups constituted less than 14%.

Table 23. Relative density of different macroinvertebrate taxa present at Rivers Kisian and Awach-Seme prior to and after weir construction, Lake Victoria Basin, Kenya.

Relative density (%) of different macroinvertebrate taxa				
Taxon	River Kisian		River Awach-Seme	
	Before weir	After weir	Before weir	After weir
Ephemeroptera				
<i>Baetis</i> sp.	12.8	16.8	11.8	16.9
<i>Caenis</i> sp.	0.5	2.1	2.6	4.8
<i>Afronurus</i> sp.	4.9	14.0	2.1	3.1
<i>Traverella</i> sp.	0.1	0.3	0.6	2.2
<i>Neophemera</i> sp.	0.1	0.2	1.1	1.1
<i>Habrophlebia</i> sp.	-	-	0.4	0.1
<i>Arthroplea</i> sp.	0.4	-	0.1	2.8
Odonata				
<i>Ophiogomphus</i> sp.	-	-	0.3	0.3
<i>Progomphus</i> sp.	-	0.3	0.4	-
<i>Chromagrion</i> sp.	0.1	-	0.2	-
<i>Erythemis</i> sp.	-	-	0.2	-
Diptera				
Chironomidae	62.9	49.1	34.4	33.0
Simuliidae	1.4	4.4	28.2	21.2
Ceratopogonidae	0.5	0.3	1.9	1.6
Tipulidae	0.3	0.3	-	0.2
Trichoptera				
<i>Hydropsyche</i> sp.	9.5	5.9	9.3	5.5
<i>Potamyia</i> sp.	1.4	1.1	0.7	2.6
<i>Macronema</i> sp.	1.0	-	1.0	0.8
<i>Rhyacophila</i> sp.	0.1	0.3	0.1	-
Coleoptera				
Gyrinidae	0.1	-	0.7	0.4
Elmidae	0.1	-	0.5	0.5
Haliplidae	0.1	-	-	0.3
Dystiscidae	-	-	0.2	0.3
Plecoptera				
<i>Acroneuria</i> sp.	-	-	0.1	0.2
Hemiptera				
Megaloptera	-	-	-	0.1
Lepidoptera				
Oligochaeta	1.6	2.4	0.6	1.1
Nematoda	0.9	1.7	2.1	1.0
Turbellaria	0.4	0.8	0.3	0.2
Hirudinea	0.1	0.2	-	0.1

$p = 0.05$

Weir installation at River Kisian mid-sampling site seemed not to affect the macroinvertebrate taxa richness since the species reported missing were rare (0.1%) (Table 23). Taxa such as *Arthroplea* sp., *Chromagrion* sp., *Macronema* sp., Coleoptera (Gyrinidae, Elmidae, Haliplidae and Dystiscidae), Plecoptera, Hemiptera, Megaloptera and Lepidoptera were missing after weir installation, though they formed rare species. In contrast, weir installation at River Awach-sume strongly affected the macroinvertebrate community. Although the taxa richness remained almost constant with 25 genera against 26 prior to weir construction, a number of new rare species were obtained after the weir installation including Tipulidae, Haliplidae, Hirudinea and Megaloptera.

4.4.2 Temporal variation in macroinvertebrate densities

Macroinvertebrate densities in both Rivers Kisian and Awach-sume increased steadily (Figure 20) from August to October (pre-weir period), with Macroinvertebrate densities being significantly higher at River Awach-sume ($t=-3.7$; d.f.=7; $p < 0.05$). Similar trends were observed at all the sampling sites when analysed individually (Figures 22 and 23) with no significant differences among sites at any of the rivers ($p > 0.05$).

After weir installation in November 2009, macroinvertebrate densities declined in both rivers, though not significantly (Figure 21), probably due to severe disturbance caused by excessive spates that occurred at the time. Mean macroinvertebrate density at the River Kisian mid-sampling site (KS2) declined though not significantly ($t = 0.25$; d.f = 3; $p > 0.05$) after the weir installation, despite the strong flooding disturbance experienced in the area during the period, suggesting that the weirs may have ameliorated the impacts of the strong disturbances events. Similar results were also observed at River Awach-sume, where mean macroinvertebrate density at sites AS1 and AS2 declined but not significantly after the weir installation ($t=0.75$; d.f. = 3; $p > 0.05$ and $t=0.60$; d.f = 3; $p > 0.05$, respectively), despite the heavy flooding, again emphasizing the possible ameliorating effect of the weirs on the macroinvertebrate community.

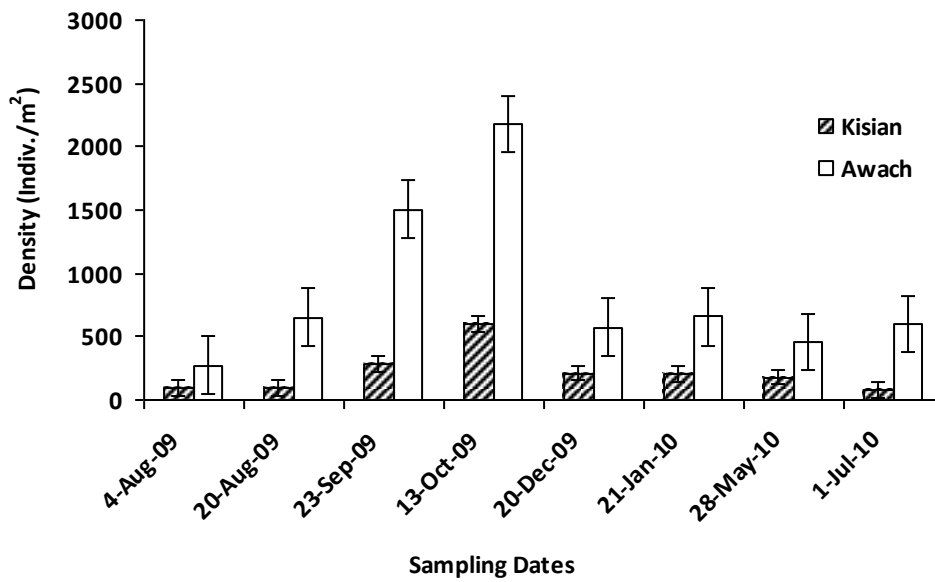


Figure 21. Macroinvertebrate density between Rivers Kisian and Awach-sume during the study period.

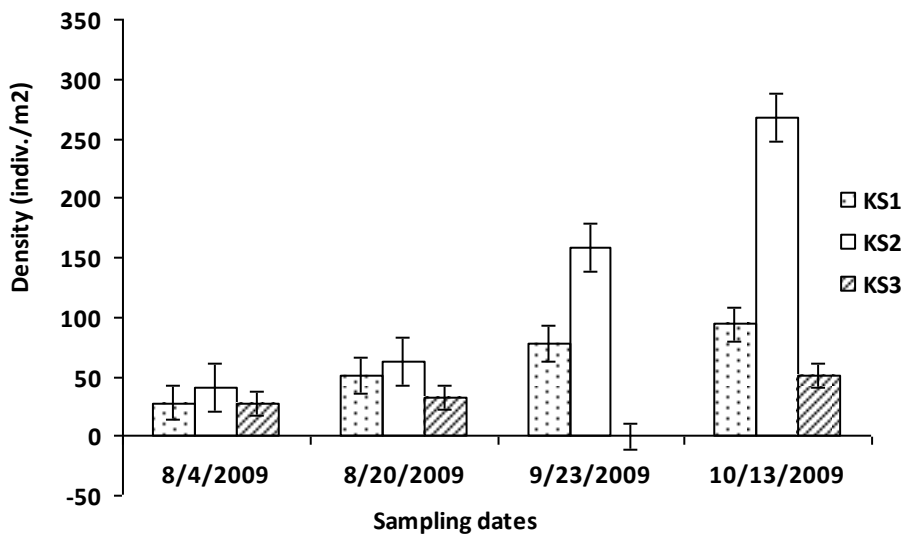


Figure 22. Macroinvertebrate density (indiv. /m²) at three sites along River Kisian before weir construction.

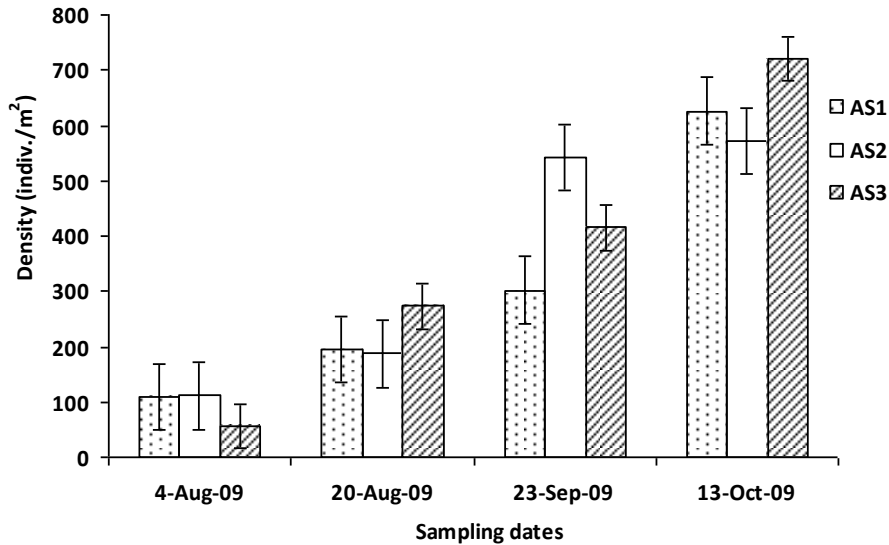


Figure 23. Macroinvertebrate density (indiv./m²) at three sampling sites along River Awach-seme prior to weir installation.

4.4.3 Macroinvertebrate species diversity, richness, and evenness

Macroinvertebrate diversity (H') at River Kisian ranged from 1.3 to 2.1 with a mean of 1.7 ± 0.17 before weir installation (Figure 24). Mean diversity among sites KS1, KS2 and KS3 did not differ significantly ($F_{2,9} = 0.77, p > 0.05$) having 1.5 ± 0.32 , 1.8 ± 0.27 and 1.2 ± 0.44 , respectively. At River Awach-seme, diversity ranged from 1.8 to 2.2 with a mean of 1.9 ± 0.09 during the pre-weir period. Mean diversity did not differ significantly ($F_{2,9}=1.8, p > 0.05$) among sites having means of 1.4 ± 0.31 at AS1, 1.8 ± 0.10 at AS2 and 1.9 ± 0.15 at AS3.

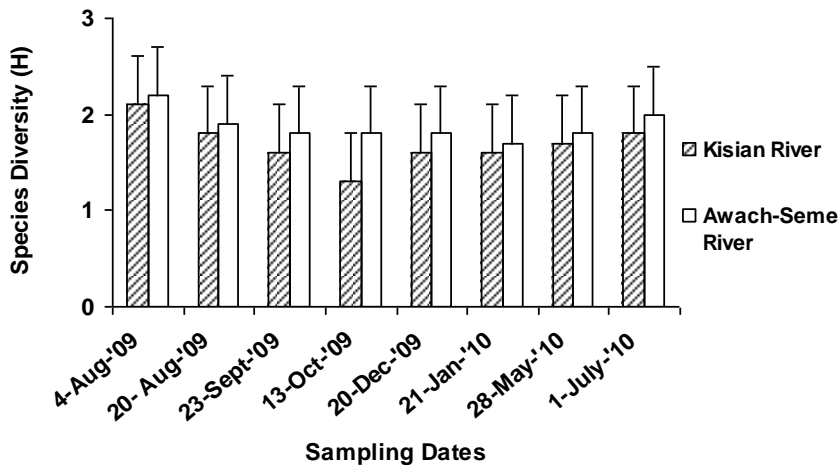


Figure 24. Macroinvertebrate species diversity at Rivers Kisian and Awach-seme prior to and after weir construction.

After weir installation, diversity at River Kisian site KS2 ranged from 1.6 to 1.8 with a mean of 1.7 ± 0.06 . Mean diversity did not differ significantly after weir installation ($t = 0.27$; $d.f = 3$; $p > 0.05$). At River Awach-seme, diversity varied from 1.7 to 2.0 with a mean of 1.8 ± 0.05 (Figure 24). Similarly, mean diversity did not differ significantly after weir installation at River Awach-seme ($t = 1.11$; $d.f = 3$; $p > 0.05$). There was no significant difference in diversity between the two rivers before weir installation ($t = -3.01$; $d.f = 3$; $p > 0.05$) however, the difference was significant after weir installation ($t = -4.33$; $d.f = 3$; $p < 0.05$).

Species richness (S) at River Kisian ranged from a low of 14 to a high of 19 prior to weir installation (Figure 25). Macroinvertebrate species richness among sites did not show a significant difference ($F_{2,9} = 0.00$, $p > 0.05$), having means of 10 ± 2.3 at KS1, 14 ± 2.5 at KS2 and 6 ± 2.3 at KS3. River Awach-seme showed a similar trend having no significant difference in species richness among sites ($F_{2,9} = 1.08$, $p > 0.05$), 15 ± 1.8 , 16 ± 0.7 and 18 ± 1.3 at AS1, AS2 and AS3 respectively.

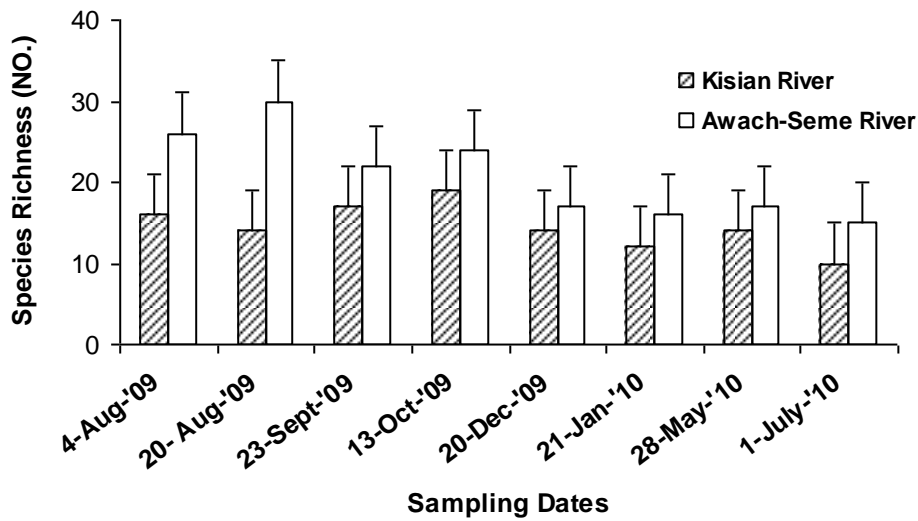


Figure 25. Macroinvertebrate species richness at Rivers Kisian and Awach-seme prior to and after weir construction.

Comparisons of species richness prior to and after weir installation depicted a non significant drop to maximum of 14, ($t = 0.41$; $d.f. = 3$; $p > 0.05$) at River Kisian site KS2. At River Awach-seme, species richness ranged from 15 to 17, showing insignificant drop after weir construction ($t = 1.3$; $d.f. = 3$; $p > 0.05$). Species evenness (E) was not significantly among between sites, within the Rivers or between the rivers (Figure 26).

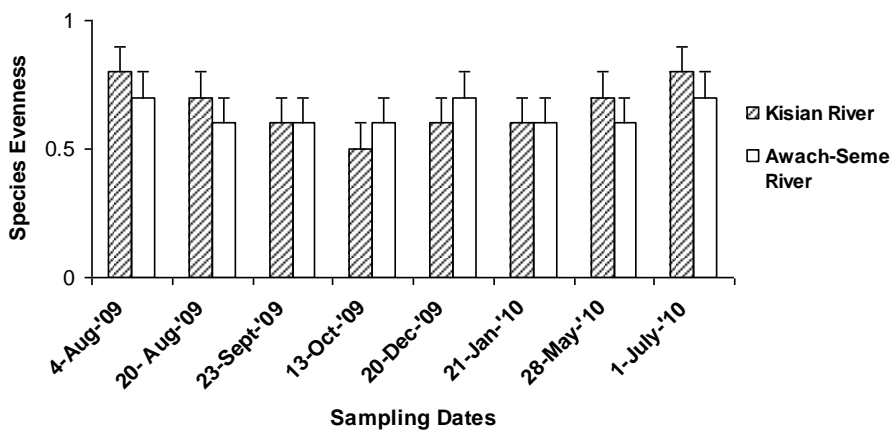


Figure 26. Macroinvertebrate species evenness at Rivers Kisian and Awach-seme prior to and after weir construction.

4.4.4 Macroinvertebrate distribution

Ephemeroptera (*Baetis* sp., *Caenis* sp. and *Afronurus* sp.), Odonata (*Progomphus* sp.), Diptera (Chironomidae, Simuliidae, Tipulidae and Ceratopogonidae), Trichoptera (*Potamyia* sp., *Hydropsyche* sp.), Coleoptera (Gyrinidae, Elmidae), Oligochaeta, Nematoda and Turbellaria were all evenly distributed at all sampling sites in both rivers. At River Awach-seme however, Plecoptera (*Acroneuria* sp.), Hemiptera, Megaloptera and Turbificidae were only found at the mid-sampling site (AS2), while Lepidoptera was only found at River Kisian. Plecoptera and Megaloptera only occurred at River Awach-seme.

4.4.5 Effect of physical and chemical characteristics on macroinvertebrate densities

Principal component analysis (PCA) showed total macroinvertebrate density to be closely related to TDS and conductivity (Figure 27). Mean water depth showed a significantly negative correlation with total macroinvertebrate density at the upper Awach-seme River site (AS1; $r = -0.75$). Other physical and chemical factors, such as (nitrates, phosphates, silicates, D.O., pH, temperature etc) showed no significant effect on the macroinvertebrate density.

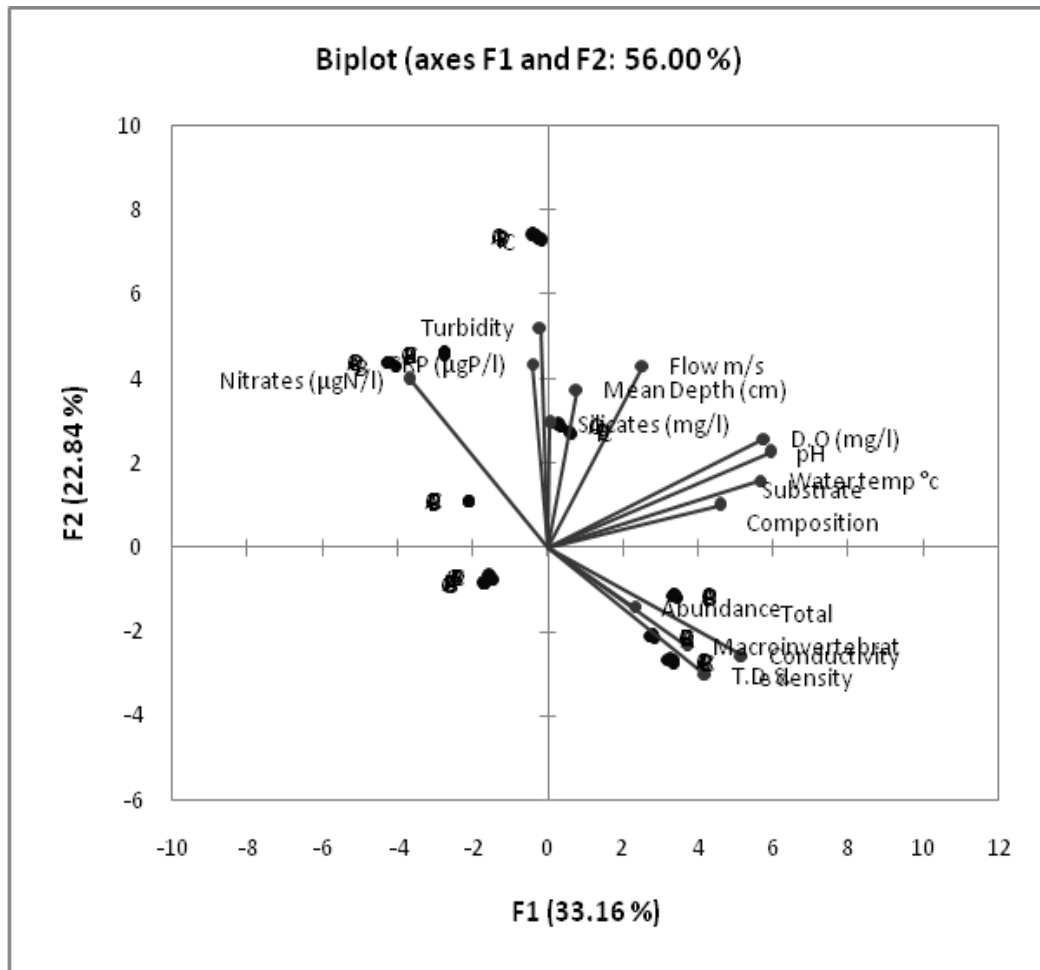


Figure 27. PCA analysis of physical-chemical parameters and macroinvertebrate taxa for the sampling period August 2009 – July 2010 (all samples on any date combined).

CHAPTER FIVE: DISCUSSION

Weirs affect the local flow velocity patterns, sediment composition and particulate organic matter (POM) budgets of streams (Pohlon *et al.*, 2007). These changes usually result in biotic responses such as changed productivity and species composition (Fjellheim, 1996). Large boulders placed on the stream bed increase channel sinuosity and flow heterogeneity (Harrison *et al.*, 2004). Water depth, velocity, water chemistry and substrate size are the best predictors of benthic invertebrate composition and distribution in streams (Litvan *et al.*, 2008; McNamara *et al.*, 2008).

5.1 Effects of boulder weir installation on physico-chemical parameters of Rivers Kisian and Awach-seme.

The results of this study showed that boulder weirs did not create the expected increase in water depth. Depth as measured within and between sampling stations were fluctuating before and after weir installation. Jowett (2003) stated that the degree of flow variability depends on rainfall variability thus changes in water level during rainy season could lead to fluctuating water depths. Dewson *et al.* (2007), studying macroinvertebrate responses to reduced discharge in small permanent streams in New Zealand observed decreased water depth following weir placement. However, Sarriquent *et al.* (2007), investigating effect of bottom substratum on macroinvertebrates in agriculturally impacted Tamoute River France, found increased water depth. In their study, Sarriquent *et al.* (2007) stated that bottom substratum created acceptable conditions in water chemistry. Roni *et al.* (2006) showed that boulder and boulder weirs had created a significant improvement in streams' physical habitats in Oregon, USA. It is likely that deeper water measured at River Kisian unlike Awach-seme could have been due to a narrow river width enhancing the formation of deep pools. Nonetheless these weirs created the expected wider and longer pools increasing the length of impact zone as confirmed by other studies (Dodd 2005).

Weirs did not substantially alter water temperature but rather created distinct physical conditions, which differ from natural reaches. Pohlon *et al.* (2007), investigating the physico-chemical characters of River Ilm in Germany found water temperature in the river column not to be affected by weirs. Zhou *et al.* (2008) stated that modified river hydrology could impact water

temperature. Rivers tend to be more dynamic in their temperature variation due to diurnal solar cycle in which water temperature is typically coolest in the morning and warmest in late afternoon.

Highest flow rate occurred after weir installation in both rivers this could be attributed to floods that occurred sporadically concurring with sampling dates. This was unexpected since boulder weir placement often results in decreased flow. This was contrary to findings of other researchers who observed reductions in flow rate following weir installation (Wood and Armitage, 1999; Dewson *et al.*, 2007; Pohlen *et al.*, 2007).

High dissolved oxygen levels at mid-reaches of Kisian and Awach-seme Rivers were partly related to faster flow rate and greater substrate heterogeneity. Alternating riffles and runs with few pools characterized these two sampling stations. Rough bottom substratum creates turbulent intensities that lead to increased dissolved oxygen levels. Cokgor and Kucukali (2005) found that boulder weir structures can appreciably increase aeration efficiency by creating turbulent conditions. Baylor *et al.* (2009), while modeling aeration efficiency of weirs in Turkey also found increased dissolved oxygen levels. Dissolved oxygen concentrations at River Kisian after weir installation were unaltered; this was consistent with those of Dewson *et al.* (2007) and Pohlen *et al.* (2007). However, Sarriquent *et al.* (2007) found decreased dissolved oxygen levels after weir placement and cited strong inputs of fine sediments as possible cause.

Boulder weirs did not have any effect on conductivity in both rivers. Similar results have been described for temperate streams; where changes in conductivity after flow reduction were negligible (Dewson *et al.*, 2007; Pohlen *et al.*, 2007). The decrease in conductivity could have been caused by increased dilution from inflows associated with shorter resident times in the river. Large fluctuations in conductivity were observed in both rivers, this can occur after periods of rainfall (Grand River Conservation Authority, Cambridge, 2009). Significantly higher levels of conductivity at River Awach-seme could have been due to additional ground water input and in-stream weathering processes (McNamara *et al.* 2008) of the watershed's bedrock and mineral salts not operating in Kisian River. Without data on ground water chemistry, it is not possible to rule out the above difference. While ground water inputs provide possible explanation for the

observed spatial variation in conductivity between the two rivers, non point runoffs of ions seems more likely.

Boulder weirs did not have effect on pH in both rivers. These results are comparable to those of Almeida *et al.* (2009), who found that weirs did not affect pH levels while studying an area of environmental preservation in D'Ouro and Santo Antônio Rivers, Brazil. Although boulder weirs modify physical habitat they appear to have little effect on physical and chemical characteristics. In essence, most physico-chemical variables did not change significantly between sampling sites after weir installation. It is predicted that such stability in pH, during the rainy season, could have been due to hydrological effects.

5.2 Effects of boulder weir placement on nutrients at Kisian and Awach-seme rivers

Two key nutrient elements affecting trophic status of waters are nitrogen (N) and phosphorus (P) (Heathwaite *et al.*, 1996). Concentrations of nitrates remained higher at upper reaches of Kisian in comparison to mid-reaches and lower reaches before weir introduction probably due to solute exclusion during the onset of rains (McNamara *et al.*, 2008). Turner and Rabalais (2003), studying the link between landscape and water quality in Mississippi River basin, showed that when soils are disturbed during cultivation, the ecological processes that keep nutrients bound up in the soil and organic matter are overpowered, and the stored nitrogen is released. Mobile nitrate-nitrogen finds its way into the rivers through surface runoff after a downpour increasing nitrate concentrations in these habitats. Heathwaite *et al.* (1996) cited arable cultivation as a source of nitrate enrichment. McNamara *et al.* (2008) pointed out that nitrate tends to remain low through increasing rains giving negative correlation with flow rate. Nitrate concentration at River Kisian remained well above those of Awach-seme during pre-weir period probably because of overuse of the riparian and agricultural activities that increased nitrate concentration at Kisian while dense riparian vegetation at Awach-seme might have buffered any runoff to the river to some degree (Heathwaite *et al.*, 1996). Nitrate concentrations at Kisian River were greatly reduced after weir introductions. Sarriquent *et al.* (2007) found similar results while working in river Tamoute, France, there; changes in water chemistry including decreased nitrates were observed. In their study Sarriquent *et al.* (2007) emphasized reduced nitrate content through respiration and denitrification.

Boulder weirs did not alter phosphate levels at Kisian and Awach-sume rivers. Rather, phosphate levels tended to fluctuate during the prolonged rain. Further, peak soluble reactive phosphate (SRP) concentrations observed in August and December 2009 may have been due to flooding that coincided with the sampling date. Similar trends were observed in total dissolved solids and silicates. Leaching of phosphate fertilizers used on the riparian zone and from laundry activities observed near the rivers could have also escalated SRP values (Pohlon *et al.*, 2007). Dunne *et al.* (2006), investigating P-impacted stream in Florida USA, stated that when site waters have SRP concentrations about 50 µg/l, soils and sediments are more likely to release P. In the present study, P-concentration fluctuated between 9.66 and 76.95µg/l at Kisian River this could be a consequence of sporadic release of phosphates as the weather patterns changed. Davis and Minshaw (1999), cited stream velocity and organic matter content as factors influencing release or retention of phosphates in rivers. During this study, changes in river hydrology and subsequently flow rate for days prior to sampling could have influenced temporal patterns in phosphate release.

Variations in silicate concentration were negligible following boulder weir installation in both rivers. This was in agreement with the results of Conley *et al.* (2000) who found that dissolved silica concentrations did not have clear differences between rivers that drain into different basins of the Baltic Sea in Sweden. Characteristics of bedrock geology of the catchment is an important factor for dissolved silica concentration of rivers (Ahmed, 2007). Thus, related soil types could have caused the insignificant variation; taking into account that major source of silicates into water bodies is through weathering of silicate containing minerals (Nyakeya *et al.*, 2009). Conley *et al.* (2000) pointed out local geology and climatology as factors that can cause insignificant difference in silicates. Ground water is responsible for maintaining vertical connectivity and stability of silicates (Almeida *et al.*, 2009). Peak concentration of silicates was also observed during May and July where highest flows occurred. Seasonal dependence could be a major influence on the temporal pattern of silicates in both rivers, as observed in other studies (Ahmed, 2007). Amount of rainfall received due to seasonal variation can influence silica concentration in rivers. Sigleo and Frick (1998), while studying seasonal variations in nutrient concentrations in a Northwestern USA watershed found silica concentrations to be greatly reduced during storm

events. They noted however, that dissolved silica load tends to increase during periods of high river discharge.

High water turbidity observed at all the sampling sites before weir installation could be due to high levels of human activities in the vicinity of the sampling stations coupled with sparse riparian vegetation cover. Low sediment values observed after weir installation were probably due to continued rains that pounded the area removing loose sediments during the onset of the rains. Turbidity was not affected by weir introductions at River Awach-seme, this was consistent with such studies as Pohlen *et al.*, (2007).

Total dissolved solids did not change markedly after weir installation in both rivers. Total dissolved solids showed significant peaks during the rains probably because of increased surface runoff from the surrounding agricultural farmlands. Heavy rains prior to sampling days led to flooding and transport of dissolved solids into the rivers. Total dissolved solids responds to spates on short term scale and weathering on long term scale (MacNamara *et al.*, 2008). Runoffs from farmland appeared to be responsible for peak values observed after weir placement in both rivers (Imbert and Stanford 1996). Adedokun *et al.* (2008) studying river systems in Ibadan Metropolis in Nigeria and Essien-Ibok *et al.* (2010) studying Mbo River also in Nigeria, stated that runoff water contributes to increased total dissolved solids in rivers.

5.3 Effects of boulder weirs on bottom substratum.

Bottom substratum experienced remarkable modification, notably increased silt deposition at Awach-seme River. The percentage covers of silt gradually increased after weir installation. Upstream of weir, flow rate was reduced creating silt dominated depositional zone. This probably explains the increased proportion of silt after weir installation. In West Iowa United States, Litvan *et al.* (2008) showed that substrate particle size was heavily influenced by boulder placements. Other substrate particle sizes including gravel and sand did not show any considerable change in their composition after weir placement.

5.4 Effect of boulder weirs on composition, density, and diversity of benthic invertebrates

Contrary to expectation that benthic macroinvertebrates density and diversity would increase after weir installation, density and diversity of the macroinvertebrates decreased though not significantly. This may have been caused by increased invertebrate drift due to increased disturbance during periods of flooding, particularly after weir placement. Floods act as an important natural disturbance (Tonkin *et al.* 2009) and high water flows are the main cause of accidental drift (Svendsen *et al.*, 2004). According to Robinson *et al.* (2004), floods often cause considerable decreases in macroinvertebrate densities. Friberg *et al.* (1998) studying macroinvertebrates of River Gelsa, Denmark, established that macroinvertebrate diversity and density both decrease for a short period following river impoundment but affirmed that macroinvertebrate community recover rapidly (within 1-2 years) exhibiting high resilience. Jowett (2003) observed that substrate stability, fine sediment deposition, water quality and food availability influence benthic invertebrate density. Changes in fine sediment composition may have directly or indirectly impacted on macroinvertebrate density and diversity at the impact sites during this study. Lack of significant variation in density and diversity of macroinvertebrates is consistent with many findings of temperate rivers. Roni *et al.* (2006), Dewson *et al.* (2007) and Sarriquent *et al.* (2007) detected non significant response of macroinvertebrates richness and density to boulder weir placements. Roni *et al.* (2006), while studying the effects of boulder weirs on aquatic biota cited amongst other reasons level of actual change produced by boulder additions as a probable reason for insignificant differences. Moreover, similar nutrients, physico-chemical parameters and hydrology between May and July 2010 could also explain observed insignificant difference in macroinvertebrate density and diversity following weir placement.

Pohlon *et al.* (2007) reported decreased macroinvertebrate species diversity after weir placement and noted that the density of macroinvertebrates was negatively correlated to flow rate. Thus, lower densities are expected in rivers with high flow. Almeida *et al.* (2009) studying a tropical stream in Brazil and Fleituch (2003) working on a temperate stream in Poland, added that alteration in stream flow regime can be considered as the main influence on density of macroinvertebrates in regulated streams. This study agrees with that observation as there was a generalized reduction in macroinvertebrates density at all sampling sites in both rivers. Velocity

affects invertebrates through its influence on dispersal and acquisition of resources, by altering characteristics of the habitat, or by affecting competition and predation (Dewson *et al.*, 2007). Thus, influence of flow rate on invertebrates differs among taxa depending on their mode of feeding and habitat requirements. Brooks *et al.* (2002) indicated that macroinvertebrate populations were more sensitive to individual site conditions than to the heterogeneity treatments, thus increasing habitat heterogeneity may be an ineffective technique if the restoration goals are to promote macro-invertebrate recovery.

Boulder weirs did not create a significant effect on macroinvertebrate diversity, richness and evenness. Ogbeibu and Oribhabor (2002) found reduced richness and general diversity of macroinvertebrates. In their study, Ogbeibu and Oribhabor (2002) stated 'habitat reduction' and 'habitat change' theories as the possible causes of this response. In this study habitat change caused by impoundment could have been the most probable reason for insignificant variation observed.

Ephemeroptera was the most diverse order followed by Diptera and Trichoptera in both rivers. However, they were the second most abundant taxa after Diptera at spatiotemporal scales. Some Ephemeroptera especially *Baetis* sp. prefer living on coarse substrate (Sarriquent *et al.*, 2007). Studies have shown that Ephemeroptera species are also sensitive to flow regulation (Marcovic and Zivic, 2002; Jackson *et al.*, 2007). Fjellheim (1996) noted that *Baetis* sp. preferred habitats with moderate to strong velocities from 0.25 and over 0.75m/s. This could have been the reason for the observed large numbers of *Baetis* Sp. given that the flow rate was within the values stated.

The higher density of chironomids in both rivers agrees with the findings in many other freshwater habitats where chironomids dominate (e.g. Epler (1995); Lencioni *et al.* (2011). Tonkin *et al.* (2009) found that Chironomidae were most numerically dominant taxa and comprised over 80% of all organisms found. In their study Tonkin *et al.* (2009) pointed out that chironomids tolerate river impoundment and were often found to thrive in regulated rivers. The dipterans, remarkably Chironomidae have been found to dominate aquatic invertebrate communities (Ogbeibu and Oribhabor, 2002; Tonkin *et al.*, 2009). Lekka *et al.* (2004) assessing

water and habitat quality of a Mediterranean river, found that Chironomidae were the most abundant family at the impact site because of their tolerance to a wide range of stressors. In this study, weir placements led to reduced densities of chironomids in both rivers. Studies by Ogbeibu and Oribhabor (2002), were in agreement expounding that significant reduction in density seemed to be chironomid's primary response to new environment created by weirs.

Results obtained from both rivers showed that numbers of *Hydropsyche* sp. decreased upon boulder placements. The decrease in *Hydropsyche* sp. density might have been a response to decreased food or increased sedimentation. Imbert and Stanford (1996) reported the opposite pattern. According to Gallardo-Mayenco and Ruiz (2007), *Hydropsyche* sp. requires an environment basically consisting of firm substrate (stones) and a medium to fast water current velocity with a moderate content of organic matter. They stated that neither water current velocity nor substrate can influence by themselves the densities of *Hydropsyche* sp.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In conclusion, the impact of weir installation on macroinvertebrate communities and water quality status was meagre. Furthermore, a local disturbance (such as spates) cancelled the beneficial effect of the restoration with disappearance of few species. It is apparent that any impoundment structures must be combined with catchment management to ensure their viability.

The following conclusions were drawn:

- 1) Sites with boulders and cobbles support diverse macroinvertebrate taxa, their distribution, and density. This indicates that sites dominated by silt or sand have fewer species which are less abundant, as was observed after weir installation due to increased siltation.
- 2) Weir placement did not affect most physical parameters and nutrients probably because prolonged rains did not allow seasonality.
- 3) There is a correlation between macroinvertebrate densities, diversities and distribution and stream depth, flow velocity and bottom substratum. These relationships may indicate that increased flow rate, increased water depth, and fine bottom sediments limit macroinvertebrate community responses.

6.2 Recommendations

- 1) Future studies should examine organic matter retention besides macroinvertebrate production; these may be appropriate indicators of change at local scale.
- 2) A long-term study should be undertaken to comprehend the spatial-temporal variation of macroinvertebrate density and diversity as well as water quality status in both rivers.
- 3) Boulder weir placement should be coupled with other measures (e.g. large woody debris) to improve habitat complexity since wood is recognized as a 'hot spot' for invertebrate diversity and production.
- 4) Any restoration work (boulder weir placement) be combined with catchment management (creation of buffer strips, protection of riparian vegetation and off stream domestic washing) to ensure their feasibility.
- 5) Future studies of this kind should investigate the effect of weir placement on macroinvertebrate drift.

REFERENCES

- Adedokun, O.A., Adeyemo, O.K., Adeleye, E. and Yusuf, R.K. (2008). Seasonal limnological variation and nutrient load of the River system in Ibadan Metropolis, Nigeria. *European Journal of Scientific Research*, 23, 98-108.
- Ahmed, R. (2007). *Seasonal variation of inorganic nutrients (DSi, DIN and DIP) concentrations in Swedish River*. Msc Thesis, Linkokings Universitet, Sweden.
- Almeida, E.F., Oliveira, R.B., Mugnai, R., Nessimian, J.L. and Baptista, D.F. (2009). Effects of small dams on the benthic community of streams in an Atlantic forest area of Southern Brazil. *International River Hydrobiology*, 2, 179-193.
- Amadalo, B., Jama, B., Niang, A., Noordin, Q., Nyasimi, M., Place, F., Franzel, S. And Beniest, J. (2003). *Improved fallows for western Kenya: an extension guideline*. World Agroforestry Centre (ICRAF), Nairobi.
- Ansari, Z.A., Sivadas, S. and Ingole, B.S. (2003). *Benthic macrofauna*. Research Report No. 8, National Institute of Oceanography, Dona Paula, India.
- Armitage, P.D. (2006). Long-term faunal changes in a regulated and an unregulated stream-cow green thirty year on. *River Research Application*, 22, 947-966.
- Balcombe, S.R., Closs, G.P. and Suter, P.J. (2007). Density and distribution of epiphytic invertebrates on emergent macrophytes in flood plain Billabong. *River Research and Applications*, 23,843-857.
- Baylar, A., Kisi, O. and Emiroglu, M.E. (2009). Modelling air entrainment rate and aeration efficiency of weirs using ANN approach. *G. U. Journal of Science*, 22, 107-116.
- Brooks, S.S., Palmer, M.A., Cardinale, B.J., Swan, C.M. and Ribblett, S. (2002). Assessing stream ecosystem rehabilitation: Limitations of community structure data. *Restoration ecology*, 10, 156-168.
- Cokgor, S. and Kucukali, S. (2005). Effects of sediment roughness on surface aeration around boulders in an open channel flow. *RMZ- Materials and Geoenvironment*, 52, 13-15.
- Collier, K.J. (2002). Effects of flow regulation and flushing on instream habitat and benthic invertebrates in a New Zealand river influenced by a volcanic eruption. *River Research and Application*, 18, 213-226.
- Conley, D.J., Stalnacke, P., Pitkanen, H. and Wilander, A. (2000). The transport and retention of dissolved Silicates by Rivers in Sweden and Finland. *American Society of Limnology and Oceanography*, 45, 1850-1853.

- Comiti, F., Mao, L., Lenzi, M.A. and Siligardi, M. (2009). Artificial steps to stabilize Mountain Rivers: A post-project ecological assessment. *River Research and Application*, 25, 639-659.
- Cowx, I.G., Van der Knaap, M., Muhoozi, L.I. and Othina, A. (2003). Improving fisheries catch statistics for Lake Victoria. *Aquatic Ecosystem Health and Management*, 6, 299-310.
- Davis, J.C. and Minshaw, G.W. (1999). Nitrogen and Phosphorus uptake in two Idaho (USA) headwater wilderness streams. *Oecologia*, 119, 247- 255
- Dewson, Z.S., James, A.B.W. and Death, R.G. (2007). Invertebrate community responses to experimentally reduced discharge in small streams of different water quality. *Journal of the North American Benthological Society*, 26, 754-766.
- Dodd, H.R. (2005). *Evaluation of Newbury weirs (rock riffles) for improving habitat quality and biotic diversity in Illinois streams*. Research report, Illinois Natural History and conservation, U.S.A.
- Dunne, E.J., Reddy, R. and Clark, M.W. (2006). Biogeochemical indices of phosphorus retention and release by wetland soils and adjacent stream sediments. *The society of wetland scientists*, 26, 1026-1041.
- Epler, J.H. (1995). *Identification manual for the Larval Chironomidae (Diptera) of Florida* Revised Edition.
- Essien-Ibok, M.A., Akpan, A.W., Udo, M.T., Chude, L.A., Umoh, I.A. and Asuquo, I.E. (2010). Seasonality in the physical and chemical characteristics of Mbo River, Akwa Ibom State, Nigeria. *Nigerian Journal of Agriculture, Food and Environment*, 6, 60-72.
- Fjellheim, A. (1996). Distribution of benthic invertebrates in relation to stream flow characteristics in a Norwegian River. *Regulated Rivers: Research and Management*, 12, 263-271.
- Fjellheim, A. and Raddum, G.G. (1996). Weir building in a regulated West Norwegian River: long-term dynamics of invertebrates and fish. *Regulated Rivers: Research and Management*, 12, 501-508.
- Fleituch, T. (2003). Structure and functional organization of benthic invertebrates in regulated streams. *International River Hydrobiology*, 88, 332-344.
- Friberg, N., Kronvang, B., Hansen, H. O. and Svendsen, L.M. (1998). Long-term, habitat-specific response of a macroinvertebrate community to river restoration. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 8, 87-99.
- Gallardo-Mayenco, A. and Ruiz, A. (2007). Distribution of microhabitat selection of Hydropsyche exocellata Dufour (Trichoptera, Hydropsychidae) in a Mediterranean river affected of organic pollution: the Guadaira River (S. Spain). *Limnetica*, 26, 89-97.

- Gonzalez, J.M. and Graca, M.A.S. (2005). Influence of detritus on the invertebrate community in a small Portuguese stream. *International Riverine Hydrobiology*, 90, 534-545.
- Gordon, N.D., Macmahon, T.A. and Finlayson, B.L. (1992). *Stream hydrology: An introduction for ecologists*. John Wiley and sons, UK.
- Gore, J.A., Crawford, D.J. and Addison, D.S. (1998). An analysis of artificial riffles and enhancement of benthic community diversity by physical habitat simulation (PHABSIM) and direct observation. *Regulated Rivers: Research and Management*, 14, 69-77.
- Gore, J.A. and Hamilton, S.W. (1996). Comparison of flow-related habitat evaluations downstream of low-head weirs on small and large fluvial ecosystems. *Regulated Rivers: Research and Management*, 12, 459-469.
- Government of Kenya (2002). *Vihiga District Development Plan for the period 2002-2008*. Vihiga District, Kenya.
- Grand River Conservation Authority (2009). *River data: water quality, conductivity in Canada*. Retrieved August 21, 2010, website: [Http://www.grandriver.ca/waterdata/conductivitydata.cfm](http://www.grandriver.ca/waterdata/conductivitydata.cfm)
- Growns, I.O. and Growns, J.E. (2001). Ecological effects of flow regulation on macroinvertebrate and periphytic diatom assemblages in the Hawkesbury-Nepean River, Australia. *River Regulations: Research and Management*, 17, 275-293.
- Harrison, S.S.C., Pretty, J.L., Shepherd, D., Hildrew, A.G., Smith, C. and Hey, R.D. (2004). The effect of instream rehabilitation structures on macroinvertebrates in lowland rivers. *Journal of Applied Ecology*, 41, 1140-1154.
- Heathwaite, A.L., Johnes, P.J. and Peters, N.E. (1996). Trends in nutrients. *Hydrological Processes*, 10, 263-293.
- Humphries, P., Davies, P.E. and Mulcahy, R.E. (1996). Macroinvertebrate assemblages of littoral habitats in the Macquarie and Mersey Rivers, Tasmania: Implications for the management of regulated rivers. *Regulated Rivers: Research and Management*, 12, 99-122.
- Imbert, J.B. and Stanford, J.A. (1996). An ecological study of a Regulated Prairie stream in western Montana. *Regulated Rivers: Research and Management*, 12, 597-615.
- Jackson, H.M., Gibbins, C.N. and Soulsby, C. (2007). Role of discharge and temperature variation in determining invertebrate community structure in a regulated river. *River Research Application*, 23, 651-669.
- Jackson, D. and Marmulla, G. (2000). *The influence of dams on river fisheries*. Retrieved 2010, from UNFAO: Fisheries Technical Paper 419 Web site <http://www.dams.org/>

- James, A.B.W., Dewson, Z.S. and Death, R.G. (2008). The effects of experimental flow reduction on macroinvertebrate drift in natural and streamside channels. *Riverine Research and Application*, 24, 22-35.
- Jowett, I.G. (2003). Hydraulic constraints on habitat suitability for benthic invertebrates in gravel-bed Rivers. *River Research and Applications*, 19, 495-507.
- Kominoski, J.L. and Pringle, C.M. (2009). Resource-consumer diversity: testing the effect of leaf litter species diversity on stream macroinvertebrate communities. *Fresh Water Biology*, 54, 1461-1473.
- Lekka, E., Kagalou, I., Lazaridou-Dimitriadou, M., Albanis, T., Dakos, V., Lambropoulou, D. and Sakkas, V. (2004). Assessment of the water and habitat quality of a Mediterranean River (Kalamas, Epirus, Hellas), in accordance with the EU water framework directive. *Acta Hydrochemistry and Hydrobiology*, 32, 175-188.
- Lencioni, V., Marziali, L. and Rossaro, B. (2011). Diversity and distribution of Chironomids (Diptera, Chironomidae) in pristine Alpine and pre-Alpine springs (Northern Italy). *Journal Limnology*, 70, 106-121.
- Litvan, M.E., Stewart, T.W., Pierce, C.L. and Larson, C.J. (2008). The effect of grade control structures on the macroinvertebrate assemblages of an agriculturally impacted stream. *River Research and Applications*, 24, 218-233.
- Marcovic, Z. and Zivic, I. (2002). Fauna of Ephemeroptera in the running waters of West Serbia. *Archeological Biological Science*, 54, 117-124.
- Matsuishi, T., Muhoozi, L., Nkumbo, O., Budeba, Y., Njiru, M., Asila, A., Othina, A. and Cowx, I.G. (2006). Are the exploitation pressures on the Nile perch fisheries resources of Lake Victoria a cause of concern? *Fisheries Management and Ecology*, 13, 53-71.
- McNamara, J.P., Kane, D.L., Hobbie, J.E. and Kling, G.W. (2008). Hydrological and biogeochemical controls on the spatial and temporal patterns of nitrogen and phosphorus in the Kuparuk River, arctic Alaska. *Hydrological Processes*, 22, 3294-3309.
- Merritt, R.W. and Cummins, K.W. (1996). *An introduction to the aquatic insects of North America*. Kendall/Hunt Publishing Company, Dubuque, IA.
- Negishi, J.N. and Richardson, J.S. (2003). Responses of organic matter and macroinvertebrates to placements of boulder clusters in a small stream of South-western British Columbia, Canada. *Canadian Journal of Fisheries and Aquatic Sciences*, 60, 247-258.

- Nyakeya, K., Raburu, P.O., Masese, F.O. and Gichuki, J. (2009). Assessment of pollution impacts on the ecological integrity of the Kisian and Kisat rivers in Lake Victoria drainage Basin, Kenya. *African Journal of Environmental Science and Technology*, 3, 097-107.
- Odada, E.O., Olago, D.O., Kulindwa, K., Ntiba, M. and Wandiga, S. (2004). Mitigation of environmental problems in Lake Victoria, East Africa: Causal chain and policy options Analyses. *Ambio*, 33, 1-2.
- Ogbeibu, A.E. and Oribhabor, B.J. (2002). Ecological impact of river impoundment using benthic macro-invertebrates as indicators. *Water research*, 36, 2427-2436.
- Pennak, R.W. (1978). *Fresh water invertebrates of the United States*. 2nd Edition, New York: John-Wiley and sons.
- Pohlen, E., Augspurger, C., Willkomm, M., Halle, S., Risse-Buhl, U., Kusel, K. and Arle, J. (2007). Querying the obvious: Lessons from a degraded stream. *Restoration Ecology*, 15, 312-316.
- Rader, R.B. and Belish, T.A. (1999). Influence of mild to severe flow alterations on invertebrate in three mountain streams. *Regulated Rivers: Research and Management*, 15, 353-363.
- Reich, P., McMaster, D., Bond, N., Metzeling, L. and Lake, P.S. (2009). Examining the ecological consequences of restoring flow intermittency to artificially perennial lowland streams: patterns and predictions from the Broken-Boosey creek system in Northern Victoria, Australia. *River Research and Applications*.
- Robinson, C.T., Aebischer, S. and Uehlinger, U. (2004). Immediate and habitat-specific responses of macroinvertebrates to sequential, experimental floods. *Journal of North American Benthological Society*, 23, 853-867.
- Roni, P., Bennett, T., Morley, S., Pess, G.R., Hanson, K., Slyke, D.V. and Olmstead, P. (2006). Rehabilitation of bedrock stream channels: The effect of boulder weir placement on aquatic habitat and biota. *River Research and Applications*, 22, 967-980.
- Sarriquent, P.E., Bordenave, P. and Marmonier, P. (2007). Effects of bottom sediment restoration on interstitial habitat characteristics and benthic macroinvertebrate assemblages in a headwater stream. *River Research Application*, 23, 815-828.
- Shannon, C.E. and Weaver, W. (1949). *The mathematical theory of communication*. University of Illinois press, Illinois.
- Shields Jr, F.D., Testa, S. and Cooper, C.M. (2009). Nitrogen and phosphorus levels in the Yazoo River basin, Mississippi. *Ecohydrology*, 2, 270-278.
- Sigleo, A. and Frick, W. (1998). *Seasonal variations in river flow and nutrient correlations in a Northwestern USA watershed*. U.S. Environmental Protection Agency, Western Ecology

Division, Newport. Retrieved September 3, 2010, website:
[Http://www.tucson.ars.ag/icuw/proceedings/sigleopdf](http://www.tucson.ars.ag/icuw/proceedings/sigleopdf).

- Soininen, J. (2004). Determinants of benthic diatom community structure in boreal streams: the role of environmental and spatial factors at different scales. *International River Hydrobiology*, 89, 2, 139-150.
- Svendsen, C. R., Quinn, T. and Kolbe, D. (2004). *Review of macroinvertebrate drift in lotic ecosystems*. Wildlife Research Program Environment and Safety Division, Seattle, WA.
- Svendsen, K.M., Renshaw, C.E., Magilligan, F.J., Nislow, K.H. and Kaste, J.M. (2009). Flow and sediment regimes at tributary junctions on a regulated river: Affect sediment residence time and benthic macroinvertebrate communities. *Hydrological Processes*, 23, 284- 296.
- Tonkin, J.D., Death, R.G. and Joy, M.K. (2009). Invertebrate drift patterns in a regulated river: dams, periphyton biomass or longitudinal pattern? *River Research and Applications*, 25, 1219-1231.
- Turner, R. E. and Rabalais, N. N. (2003). Linking Landscape and Water Quality in the Mississippi River Basin for 200 Years. *Bioscience*, 53, 563-572.
- Van Zyll De Jong, M.C., Cowx, I.G. and Scruton, D.A. (1997). An evaluation of in-stream habitat restoration techniques on Salmonid populations in a Newfoundland stream. *Regulated Rivers: Research and Management*, 13, 603-614.
- Wetzel, R.G. and Likens, G.E. (2000). *Limnological analyses*. Springer-Verlag Inc. New York.
- Wood, P.J. and Armitage, P.D. (1999). Sediment deposition in a small lowland stream – Management implications. *Regulated Rivers: Research and Management*, 15, 199-210.
- Zhou, S., Tang, T., Wu, N., Fu, X. and Cai, Q. (2008). Impact of a small dam on riverine zooplanktons. *International River Hydrobiology*, 93, 297- 311.

APPEDICES



Plate 7. Gabion weir constructed at Mid-stream Kisian River (site KS2), following the breakdown of boulder weirs.



Plate 8. Boulder weir at Upper Awach-seme site AS1 showing a pool formed a head of the weir.



Plate 9. Boulder weir at mid Awach-seme site AS2 showing trapped Course particulate organic matter (CPOM) over the weir crest



Plate 10. Human activities that negatively impact on the ecosystems of both Kisian and Awach-
seme Rivers.

Appendix I: Plates 7 to 10 showing photos of boulders weirs and some human activities that negatively impact on the riverine ecosystem of Awach-seme and Kisian.