INFLUENCE OF PLANTED RIPARIAN BUFFER VEGETATION COVER AND WATER QUALITY ON THE BENTHIC MACROINVERTEBRATE ASSEMBLAGES IN KUYWA RIVER, BUNGOMA COUNTY, KENYA

BY

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DECLARATION

Declaration by the candidate:

This is my original work and has not been submitted for a degree in any other university.

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DEDICATION

The success of this thesis is dedicated to my

Wife (Dr. Florence Oruta), for her encouragement

To take this step in my life, and my special children

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ABSTRACT

The Kuywa River watershed has undergone riparian vegetation planting since 2006 in order to improve the river health. Studies undertaken elsewhere have investigated how environmental factors affect ecosystem processes and functionalities but fail to show how planted riparian vegetation and water quality parameters influence the structure of the benthic macroinvertebrates. These studies also focus on disturbances on natural riparian vegetation but fail consider the influence of planted riparian vegetation on benthic macroinvertebrate assemblages. Furthermore, limited studies in Kenya have documented the influence of planted riparian cover and water quality parameters on benthic macroinvertebrate assemblages. Therefore, the purpose of this study was to assess the influence of planted riparian vegetation cover and water quality parameters on benthic macroinvertebrate assemblages in Kuywa River. The specific objectives were to: establish the influence of water quality parameters on benthic macroinvertebrate assemblages in the Kuywa River; to determine the influence of planted riparian vegetation cover on benthic macroinvertebrate species abundance in the Kuywa River; and analyse the relationship between temporal variation for water quality parameters and benthic macroinvertebrate assemblages in Kuywa River. The study adopted a mix of empirical cross-section descriptive and longitudinal research designs. Nine sites, were identified to represent the whole length of the Kuywa River. Primary data were collected four times between January and October, 2016 to cover dry and wet seasons. Benthic macroinvertebrate sampling was carried out using a 250 µm mesh dip net. In-situ water quality parameters were measured using a standardized electronic meters. The water quality parameters requiring laboratory analyses (nitrites, nitrates, and sulphates) were collected and transported to the laboratory for analysis. Data analyses employed descriptive statistics which included comparison of Richness Index (S), Abundance Index (N), Margalef Richness (d) and Shannon Index (H). It also used inferential statistics Spearman rank correlation, PCA, BIO-ENV BEST, MDS, ANOSIM, SIMPER and SIMPROOF. The study established that Elassoneuria sp., Ephemerella sp., Macrobdella sp. abundance were positively correlated to altitude ($\rho<0.01$), Elassoneuria sp., Ephemerella sp., Synclita sp., Macrobdella sp., Hydropsyche sp. and Baetis sp. were positive correlated to oxygen concentration ($\rho<0.05$) but were negatively correlate to total nitrogen ($r=-0.72$, $\rho= 0.015$). Megalagrion sp., Baetis sp., and Elmnae sp. abundance were significantly negative correlated to nitrites and nitrates. Hexatoma sp., Belostoria sp., and Simulium sp. were significantly positive correlated to percentage vegetation cover ($\rho=0.01$) while sites KG and T2 which had good riparian vegetation cover had the highest species richness (35). Temporal variation in water quality parameters influenced benthic macroinvertebrate assemblages, dry season recording 2,330 and wet 5,112 individuals. Dry season had higher species evenness (ranging 0.5 to 0.8) than wet (0.2 to 0.8). EPT species richness was found to be higher during the wet season (range 0.3 to 5.4). This result demonstrated that riparian vegetation cover favoured sensitive benthic macroinvertebrate species in Kuywa River while sites with poor vegetation cover favoured tolerant species. Equally, wet season favoured more benthic macroinvertebrates than dry season due to dilution influence of higher water discharge in wet season. The planting of riparian vegetation should be increased along the Kuywa River and should begin from the headwaters down through the catchment and a continuous buffer length be achieved.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOSIM	Analysis of Similarity
ASO	August, September and October
AusRivAs	Australian River Assessment Scheme
BBMW	British Biological Monitoring Working
BIO-ENV	Biota Environmental matching
CPOM	Coarse particulate organic matter
EPT	Ephemeroptera, Plecoptera and Tricoptera
FPOM	Fine particulate organic matter
FWD	Fine woody debris
GoK	Government of Kenya
LWD	Large woody debris
MAM	March, April and May
MDS	Multi-Dimensional Scaling
mg/l	Milligram per litre
MVA	Multivariate analysis
NWRMD	National Water Resources Management and Development
O/E	Observed divided by Expected
PCA	Principal Component Analysis
SE	Standard Error
PRIMER	Plymouth Routines In Multivariate Ecological Research
SIGNAL	Stream Invertebrate Grade Number – Average Level
SIMPER	Similarity Percentages
SIMPROF	Similarity Profile
SPEAR	Species At Risk

SPSS	Statistics Package for Social Sciences
WRMA	Water Resources Management Authority
µs/cm	Micro-Siemens/centimetre

DEFINITIONS OF TERMS

Riparian zone: A riparian zone is the area interface between land and a river or stream.

Planted riparian buffer vegetation cover:

The planted riparian buffer vegetation cover in this document comprised the percentage cover of the trees planted on the riparian zone and the herbs, shrubs and grass which emerge after fencing off the land. The influence of riparian vegetation cover for this study included the influence of canopy cover. The planted riparian vegetation are considered from the time the project was initiated (2006) to the present. Thus the planted riparian vegetation being at different level of maturity.

River health:

A healthy river is one that is similar to a pristine one of the same type in terms of physico-chemical and macroinvertebrate assemblages. A healthy river will have properties and functions of physico-chemical and macroinvertebrate assemblages mimicking those in natural un-impacted streams of the same locality. Macroinvertebrate assemblages in a health river will balance between tolerant and intolerant species richness, abundance and evenness.

Benthic macroinvertebrate assemblages:

A macroinvertebrate is the term used for invertebrate fauna that can be captured by a 500µm net or sieve. This includes arthropods insects, mites, scuds and (crayfish), molluscs snails, limpets, mussels and clams, annelids segmented (worms), nematodes (roundworms), and platyhelminthes (flatworms).They inhabit all types of running waters, from fast-flowing mountain streams to slow moving muddy rivers. In this study, macroinvertebrate assemblage includes abundance and diversity.

Benthic zone:

The benthic zone is the ecological region at the lowest level of a body of water such as an ocean, a lake, or river, including the sediment surface and some sub-surface layers. Organisms living in this zone are called benthos, e.g. the benthic invertebrate community. In a stream this zone may include areas which are only a few inches below the water.

Water Quality Parameters

These are physico-chemical variables which define aquatic environment for benthic macroinvertebrates. In this document they include pH, temperature, turbidity, total dissolved solids, suspended solids, dissolved oxygen, nitrites, nitrates, sulphates, total nitrogen, total phosphorus, phosphorus, stream width, altitude and stream discharge.

Kuywa River:

The main trunk of Kuywa River and its main tributaries such as Kibingei, Kibisi and Bokoli. Sampling was taken within main trunk of Kuywa River and at points where main tributaries joint the main Kuywa River trunk.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the study

River health has become of global concern to water resource managers and users (Gregory, Swanson, McKee, and Cummins (1991); (Sponseller, Benfield, & Valett, 2001; Wantzen, Ramirez, & Winemimller, 2006). Prior to the 1990s, river health assessment mainly relied on water quality measures; however, in more recent times, assessment programs have focused on the direct measurement of characteristics of the biota (mainly benthic macroinvertebrates, algae, vegetation, and fish) or ecosystem processes ,(e.g. Angradi et al., (2011); Bunn et al., 2010; Metcalfe-Smith, (1996)). A holistic approach to assessing the health of a river system is to apply multimetric methods which combine parameters that represent the biological, chemical, and physical aspects of ecosystems (e.g., Bunn et al., (2010); Davies, Harris, Hillman, & Walker,(2010); Ladson & White, (1999); Zhao, Yang, & Yao, (2005)). Riparian vegetation provides both physical and biological aspects to determine river health. Studies indicate that riparian zone vegetation provide a buffering effect on rivers and streams thus sustaining their health (Growns, Rourke, & Gilligan, 2013; Masese et al., 2013; Sheldon et al., 2012).

Globally, studies have been carried out to establish the importance of riparian zone vegetation in determining geomorphology, structure of river valley floor landforms and riparian interactions (Gregory, Swanson, McKee, & Cummins, 1991; Buchanan, Nagle, & Walter, 2014). In USA, Naiman and Decamps (1997) established how riparian zone vegetation interacts with macroinvertebrates by observing the linkages between macroinvertebrates, vertebrates and microinvertebrates. However, much of the studies in USA are devoted to response of macroinvertebrates to urbanization (Chadwick, Thiele, Huryn, Benke, &

Dobberfuhl, 2012; Paul & Meyer, 2001; Utz & Hilderbrand, 2011; Walsh et al., 2005). Other studies in Queensland Australia and New Zealand which deal with restored riparian vegetation observe the functions rendered by the macrophytes in processes such as denitrification and biomass changes (Fellows et al., 2006; Kennedy & Turner, 2011; Parkyn, Davies-Colley, Halliday, Costley, & Croker, 2003; Sheldon et al., 2002; Sheldon et al., 2012). In La Choza stream, Argentina, Cortelezzi, Ocón, Oosterom, Cepeda, & Capítulo, (2015) experimentally investigated the effect of nutrient enrichment on macroinvertebrate assemblages whereby only two taxa had significant response. In these studies, environmental factors are observed on how they affect the ecosystem processes and functionalities. The findings from these studies indicate mixed response on the influence on how water quality parameters influence the structure of the benthic macroinvertebrates calling for more investigations.

In Africa, the concept of stream restoration by governments financing the planting of riverine vegetation started in the present decade (Kibichii, Shivoga, Muchiri, & Miller, 2007). More so, limited number of African countries have established a formal monitoring program to monitor changes in river systems by investigation the structure of macroinvertebrates (Odume, Muller, Arimoro & Palmer, 2012). The South African River Health Monitoring Program investigates the macroinvertebrate assemblages in different rivers under different disturbance gradients (Nojiyeza, 2013). Both in Uganda and Tanzania, the Lake Victoria Environmental Management Program (LVEMP) investigated the characteristics of macroinvertebrate and microinvertebrates assemblages in Lake Victoria and its rivers in natural and disturbed gradients (Njiru, Kazungu, Ngugi, Gichuki, & Muhoozi, 2008). Studies have been carried out in upland rivers of the Usambara Mountains of Tanzania to evaluate the impacts of tea cultivation in adjacent stream ecosystems (Biervliet, 2009). Biervliet, (2009) established that streams surrounded by tea were characterised by significantly lower dissolved oxygen and had lower total species richness and number of families. Further, studies have been undertaken in Msimbazi River, Tanzania with the aim of identifying the type of waste, their potential sources, and the assemblage of macroinvertebrate taxa that have been affected by waste disposal in the river (Shimba, Mkude, & Jonah, 2018). These previous studies in Africa focused on disturbances on natural river vegetation and their impact on macroinvertebrates. Furthermore tea cultivation may have different disturbance gradient that indigenous vegetation since tea cultivation involves application of fertilizers and pesticides. Thus, limited studies have been carried out to investigate the influence of planted riparian vegetation cover on benthic macroinvertebrate assemblages attributes.

In Kenya, a number of studies have been undertaken by using macroinvertebrates as an indicator of river health (Kilonzo et al., 2014; Makoba, Shivoga, Muchiri, & Miller, 2008; Kibichii, Shivoga, Muchiri, & Miller, 2007; Orwa et al., 2013). In the Mara River physico-chemical water quality parameters under different land have been investigated and how they affect spatial distribution of benthic macroinvertebrates (Kilonzo et al., 2014; Minaya, MClain, Moog, Omengo, & Singer, 2013). Further, in the Mara River classification of shredder using gut contents has been carried out at different pollution gradients (Masese et al., 2013). In river Nyangores and Amala, both tributaries of Mara River, Anyona et al. (2014) investigated the effect of anthropogenic activities including the effect of solid waste on physico-chemical parameters and benthic macroinvertebrates living in river sediments. In the Njoro River, Kibichii et al. (2007) investigated the influence of land use changes in the catchment on macroinvertebrate assemblages. On the other hand, Raburu, Masese, and Mulanda (2009) developed a macroinvertebrate Index of Biotic Integrity for monitoring rivers in the upper catchments of Nyando and Nzoia Rivers. Furthermore, Ndaruga, Ndiritu, Gichuki, and Wamich (2004) established the relationship between water quality parameters and macroinvertebrate assemblages in Getharaini drainage in central Kenya. Despite a wide range of studies in Kenya dealing with microinvertebrates and land use practices, only a few of them consider have documented the influence of canopy cover on benthic macroinvertebrate composition in Kenya.

In Kenya limited studies have been undertaken on the influence of seasons on the benthic macroinvertebrates. In the Njoro River, Makoba et al.(2008) investigated the influence of seasonality and point source effluent pollution on the water chemistry and the structure of benthic invertebrate but did not consider the influence of riparian zone vegetation.

Studies carried out on Kuywa watershed in 2012 (Nyakora & Ngaira, 2014) established a successful start to the projects outlined in KUWRUA's SCMP, though they were at different stages of implementation. Further, Water Resource Management Authority (WRMA) evaluated, the performance of Kuywa Water Resource Users Association (WRUA) performance in 2014 and indicated the successful progress implementation of Integrated Water Resource Management tool (Water Resource Management Authority (WRMA), 2014). One of the projects started by KUWRUA that was considered a success was the rehabilitation of the riparian zone of Kuywa River and its tributaries (Nyakora & Ngaira, 2014). The major aim of rehabilitating the Kuywa riverine was to restore its original vegetation and re-gain the environmental value that the community used to receive (WRMA, 2014). However, in Kuywa River, no pre or post- restoration assessment of river biodiversity condition has been done during the rehabilitation program. The relationship between temporal variation of physical-chemical variables and benthic macroinvertebrate assemblage characteristics in the Kuywa River has not been established.

1.2 Statement of the Problem

The Kuywa River watershed has undergone riparian vegetation planting since 2006 in order to improve the river health. The planted riparian buffer zone vegetation introduced was intended to reverse the impacts of negative land use changes by improving channel stability, promote biodiversity, and improve water quality. The reports by WRMA and KUWRUA indicate that 37KM out of 97KM of Kuywa River riparian has been re-vegetated. Studies undertaken elsewhere have investigated how environmental factors affect ecosystem processes and functionalities but fail to show how water quality parameters and planted riparian vegetation cover influence the structure of the benthic macroinvertebrates. These studies also focus on disturbances on natural riparian vegetation and the subsequent impacts without considering the influence on benthic macroinvertebrate assemblages accruing from the planted buffer vegetation after rehabilitation. Limited studies in Kenya have documented the influence of vegetation cover over the rivers on benthic macroinvertebrate assemblages. These limited studies have concentrated on natural riparian vegetation and none has considered the planted vegetation. Furthermore, the literature reviewed reveal that no such a study has been done along the planted riparian zones of Kuywa River. Therefore, the purpose of the study was to assess the influence of riparian buffer vegetation cover and water quality on benthic macroinvertebrate assemblages (abundance, diversity and evenness) in Kuywa River.

1.3 Objective of the study

The overall objective of this study was to assess the influence of planted riparian buffer vegetation cover and water quality on benthic macroinvertebrate assemblages in Kuywa River. The specific objectives were:

1. To establish the influence of water quality parameters (Stream discharge, stream depth, turbidity, pH, dissolved oxygen, temperature, altitude, sulphates, total phosphorus, nitrites, nitrates, total suspended solids and total nitrogen) on benthic macroinvertebrate assemblages (species abundance, richness, evenness, diversity and EPT (Order Ephemeroptera, Plecoptera and Tricoptera) characteristics) in the Kuywa River.
2. To determine the influence of planted riparian vegetation cover on benthic macroinvertebrate species abundance in the Kuywa River.
3. To analyze the influence of temporal variation of water quality parameters (Stream discharge, stream depth, turbidity, pH, dissolved oxygen, temperature, altitude, sulphates, total phosphorus, nitrites, nitrates, total suspended solids and total nitrogen) on benthic macroinvertebrate assemblage (species abundance, richness, evenness, diversity and EPT (Order Ephemeroptera, Plecoptera and Tricoptera) characteristics) in the Kuywa River.

1.4 Research Hypotheses

1. Water quality parameters (Stream discharge, stream depth, turbidity, pH, dissolved oxygen, temperature, altitude, sulphates, total phosphorus, nitrites, nitrates, total suspended solids and total nitrogen) have no significant influence on benthic macroinvertebrate assemblages (species abundance, richness, evenness, diversity and EPT (Order Ephemeroptera, Plecoptera and Tricoptera) characteristics) in the Kuywa River
2. Planted riparian zone vegetation cover does not significantly affect benthic macroinvertebrate species abundance in the Kuywa River;

3. Temporal variations of water quality parameters (Stream discharge, stream depth, turbidity, pH, dissolved oxygen, temperature, altitude, sulphates, total phosphorus, nitrites, nitrates, total suspended solids and total nitrogen) have no significant influence on benthic macroinvertebrate assemblage (species abundance, richness, evenness, diversity and Ephemeroptera, Plecoptera and Tricoptera characteristics) in the Kuywa River.

1.5 Significance of the study

The study aimed to assess the influence of riparian buffer vegetation cover and water quality on benthic macroinvertebrate assemblages in the Kuywa River. The study assessed the current status of the water quality and benthic macroinvertebrate assemblages which set a bench mark for future monitoring of the Kuywa River. The findings of the study demonstrated that the ratios of the various species could be used as surrogate for ecosystem attributes to assess the health of the streams. The findings of this study is particularly important to the community and water resource managers in strengthening management strategies for the Kuywa River. The greater demand for adequate water of satisfactory quality demands that rivers and streams be of good health to satisfy different water uses. Thus the rivers with appropriate riparian vegetation cover and of recommended water quality parameters will support desired macroinvertebrates which in turn will perform processes for river health maintenance. The data generated from this study could be used by the community and water resource managers as bench mark for future monitoring in terms of longitudinal and seasonal trends in water quality variables and then relate to spatial distribution of benthic macroinvertebrate to river water quality.

1.6 Justification of the study

Kuywa River had been degraded as a result of degraded catchment particularly from the anthropogenic activities. Degradation of the Kuywa River led to community and the Government of Kenya to establish a way of rehabilitating it so as to restore its original health. The rehabilitation work need to be assessed to find out whether there has been any influence on the health of this river. The health of the river is seen in two perspectives that is in terms of water quality parameters and macroinvertebrate assemblage characteristics. Further, the study could yields information to justify the need to allocate more resources to stream rehabilitation in terms of planting riparian vegetation.

1.7 The scope and limitations of the study

1.7.1 Scope

The study was basically concerned with establishing the influence of riparian buffer vegetation cover and water quality on the benthic macroinvertebrate assemblages in the Kuywa River. It was conducted in Kuywa River, in Bungoma County, Kenya. The study was carried out between the months of January to October, 2016 using cross sectional descriptive research design. The study also employed longitudinal research design to capture the influence of seasonality on water quality parameter and benthic macroinvertebrates. The sample size comprised of nine study sites representing different sections of the Kuywa River and the data was collected through measurement of in-situ variables, collection of water samples, riparian vegetation observation and collection of benthic macroinvertebrate samples. Benthic macroinvertebrates collected were surface aquatic macroinvertebrates. Water quality parameters included temperature, turbidity, total dissolved solids, total suspended solids, dissolved oxygen, conductivity, pH, total nitrogen, total phosphorus, sulphates, nitrites and nitrates. Benthic macroinvertebrates were collected in terms of abundance according to their species and orders.

1.7.2 Limitations

This research had a limitation of having the Kenyan identification keys for classification of macroinvertebrates, therefore the researcher used the South African Keys since the environmental conditions in terms of climate are relatively the same. South Africa is a temperate region which might have limited the identification of endemic species in Kuywa River. Sampling was done along the main trunk of the Kuywa River, however, to increase effectiveness in generalization, sampling was also carried out where major tributaries joint the Kuywa River. This captured the influence of such tributaries to the health of the main Kuywa River. In terms of identifying the control site, the study had a limitation of accessing a pristine site since non-impacted sites were located in a national park interior in a forest, not accessible by road. Alternative site near the edge of the national park was considered as a control site.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter provides a theoretical overview of the previous studies that have explored the influence of riparian vegetation cover on the health of rivers. This review seeks to demonstrate and justify the need for undertaking the current study. The chapter demonstrates the knowledge, including vocabulary, theories, key variables and phenomena available on importance of riparian zone vegetation cover on the health of rivers. Further, this chapter delineate research problem, seeking new lines of inquiry, distinguishing what has been done from what needs to be done. Furthermore, this chapter establishes how the new research advances the previous research. Literature review for this study is done based on themes derived from the specific objectives. They include: Relationship between water quality parameters and macroinvertebrate assemblage attributes; the relationship between planted riparian zone vegetation cover and macroinvertebrate assemblage attributes; the temporal and spatial variations of macroinvertebrate communities in relation to canopy cover; the relationship between temporal physic-chemical parameters and temporal macroinvertebrate assemblage characteristics.

2.2 Influence of water quality parameters on macroinvertebrate assemblage attributes

Several theories have been advanced to describe the relationships between water quality parameters and benthic macroinvertebrate attributes. According to Bunn, Davies, and Mosisch (1999); Reid, Delong, and Thoms (2012); Sheldon and Walker (1997), macroinvertebrates are excellent indicators of river health due to their rapid response to environmental changes. They take part in important ecological processes, such as decomposition and nutrient cycling, and play a major role in food webs as both consumers and prey (Mendes, Calapez, Elias, Almeida, & Feio, 2014; Perera, Wattavidanage, & Nilakarawasam, 2012). Physical-chemical factors known to affect macroinvertebrates are those biophysical processes that may cause some organisms to increase in abundance while prohibiting others (Marchant, Hirst, Norris, & Metzeling, 1999). Further, Baptista et al. (2007), Rosenberg and Resh (1993) and Arimoro, Obi-Iyeke, and Obukeni (2012) argue that the use of benthic macroinvertebrates as biological indicators has gained more emphasis in river health assessment, because these organisms are affected by changes in the natural variables of rivers such as width, depth, type of substratum, water velocity and physicochemical variables which are provoked by both natural and human activities. Both propositions suggest that macroinvertebrates are important in river health monitoring. However they both fail to address the relationships which exist between the water quality parameters and macroinvertebrate assemblages in different ecological zones of the world.

The structure of physical habitat together with water quality parameters have received attention in studies as important elements of environmental quality and as agents structuring aquatic biotic assemblages (Ligeiro et al., 2013; Sály, Takács, Kiss, Bíró, & Erõs, 2011). Thus, in assessing the river health using macroinvertebrates it is important to understand the interactions among physical habitat features, water chemistry, and aquatic assemblages so as to be successful in the conservation of headwater streams (Nerbonne & Vondracek, 2001; Pinto, Araujo, Rodrigues, & Hughes, 2009). However, different macroinvertebrate communities react differently to changes in physical habitats and the water chemistry and have a broad range of tolerance to stressors (Flinders, Horwitz, & Belton, 2008), while they are important in various food webs (USEPA, 2009). Some macroinvertebrate species are endemic for specific geographical location to the other which may lend them enter into natural processes at different phases contrary to the literature cited. The differential physical habitats conditions, water chemistry and stressors necessitates research be carried out in different regions including Kuywa River to establish how different macroinvertebrates species respond to the stressors.

The importance of macroinvertebrate as an indicator of river health has been underscored (Growns et al., 2013; Mendes et al., 2014; Perera et al., 2012; Sheldon et al., 2012; Xu & Liu, 2014) as they take part in important ecosystem processes. Previous studies indicated factors that affect macroinvertebrate assemblage to included physical habitat structure, chemical properties and biological relationships (Flinders, Horwitz, & Belton, 2008; Ligeiro et al., 2013; Masese, Muchiri, & Raburu, 2009; Nerbonne & Vondracek, 2001; Nyakora & Ngaira, 2014; Parkyn et al., 2003; Pinto et al., 2009; Sály et al., 2011; USEPA, 2009; Zhao et al., 2013). In these studies, environmental factors are observed on how they affect the ecosystem processes and functionalities. However, the studies do not show how water quality parameters influence the structure of the macroinvertebrates.

Furthermore, many of the factors that contribute to diverse invertebrate communities may only be achieved over long time scales (Parkyn et al., 2003). As much as some water quality variables (e.g., visual clarity) can recover quickly from fencing livestock out of streams, other variables such as temperature moderation and provision of instream shade may take decades (Reisinger, Blair, Rice, & Dodds, 2013). Physicochemical variables leading to physical habitat structure such as woody debris in streams may take centuries to develop (Reisinger et al., 2013). But even when the physicochemical variables are favourable inadequate colonisation may be limited due to lack of pathways for macroinvertebrates to colonise the new sites (Newham et al., 2011; Parkyn et al., 2003; Sheldon et al., 2012). Therefore, rehabilitation of streams will be most successful when planting riparian zones begins from the headwaters down through the catchment and a continuous buffer length is achieved (Nyakora & Ngaira, 2014; Zhao et al., 2013). The studies carried out are mostly one time sampling and tend to give suggestion for a longitudinal approach. None of these studies at the same time looks at streams where deliberate efforts have been made to plant such vegetation and assess the progressive improvement of the river health.

Although physical habitat is the fundamental template for life and ecosystem processes in streams, Allan (1995) and Maddock (1999) consider that methods to link physical habitats to the macroinvertebrate assemblages have lagged behind those for water chemistry and ecological assessment. Limited studies however have tried to demonstrate scientifically and acceptability of the fact that physical habitats should be combined with water chemistry to study river health (Boulton, 1999; Anyona et al., 2014; Tiago et al. 2015). Nonetheless, inclusion of physicochemical variables in most indices of stream health assessment seems mandatory (Ladson & White, 1999; Zhao et al. 2013) and there is need for more inclusion of hydrological, fluvial, and other physical variables be included to establish how they affect macroinvertebrates in river systems. The few studies which assess stream ecosystem by looking at physical variables are mostly concentrated at the tropical and sub-tropical areas. These studies do not consider the streams originating from mountainous areas of equatorial regions which may have unique characteristics.

2.3 Riparian zone vegetation cover and macroinvertebrate assemblage attributes

Although definition of riparian zone differ among researchers, it encompases the stream channel between the low and high water marks and that portion of the terrestrial landscape from the high water mark toward the uplands where vegetation may be influenced by elevated water tables or flooding and by ability of the soil to hold water (Naiman & Decamps, 1997). However, the vegetation outside the riparian zone that is not directly influenced by hydrologic conditions but that contributes organic matter (e.g. leaves, wood,dissolved materials) to the flood plain or channel form part of the riparian (Gregory et al., 1991). Furthermore more interio vegetation at the ridge may influences the physical regime of the flood plain or channel by shadding may be considered part of riparian zone (Gregory et al., 1991; Monoury, Gilbert, & Lecerf, 2014). These attributes suggest that riparian zones are key systems for regulating aquatic-terrestrial linkages (Dudgeon et al., 2006; Newham et al., 2011) and that they may provide early indicators on changes in river health. The differential definition of riparian zone may account for differential investigation of river health by different researchers. Nonetheless, only little is known on the relationship among the geomorphic processes, terrestrial plant succession, and aquatic ecosystems in riparian zones.

Earlier studies have shown that local riparian, instream factors and landscape explain most of the composition and structure of macroinvertebrate assemblages in streams (Johnson, Breneman, & Richards, 2003; Johnson, Furse, Hering, & Sandin, 2007; Mosisch, Bunn, Davies, & Marshall, 1999; Sandin & Johnson, 2004; Stazner & Higler, 1986). Indeed, the structure of species assemblages requires inclusion of variables acting at multiple scales, such as instream, riparian and landscape scale within a catchment (Palmer et al., 2005; Sheldon et al., 2012; Suriano, Fonseca-Gessner, Roque, & Froehlich, 2011; Wahl, Neils, & Hooper, 2013). A holistic approach to assessing the health of a river system is to apply multimetric methods which combine parameters that represent the biological, chemical, and physical aspects of ecosystems (e.g., Bunn et al. 2010, Davies et al. 2010, Ladson and White 1999, Zhao et al. 2005). As argued by Monoury et al. (2014) the riparian vegetation provide instream production through light interception and allochthonous organic matter used as food and habitat by aquatic macroinvertebrates. These studies mostly were carried out in temperate regions whose riparian trees shed their leafs in autumn. The shedding of leafs provide materials for aquatic fauna. Equally, these studies concentrate in considering the vegetation cover at a Regional scale which may be a bit general. These studies fail to investigate the influence of riparian zone strip on river health at a given section of the stream more especially with the equatorial regions where trees may not shed their leafs frequently.

Riparian zone vegetation normally comprises diverse, dynamic and complex systems, such that the ecosystem functioning depends on the composition and characteristics of flora (Kim, Yeom, & An, 2014; Masese et al., 2013; Sheldon & Fellows, 2010). Among the dynamic and complex systems is its function in; provision of critical habitat and corridors for terrestrial wildlife (Naiman & Decamps, 1997), provision of habitat for aquatic organisms to ensure protection of surface water quality and quantity (Growns, Rourke, & Gilligan, 2013), and the control of the temperature of streams through canopy shades (Zhao, Mu, Tian, Jiao, & Wang, 2013). Furthermore, it prevents bank erosion by stabilizing bank soils through roots (Naiman & Decamps, 1997; Nyakora & Ngaira, 2014). Although this literature seem to be rich in explaining the complexity to sustain both simple and complex food-web in the rivers, it fails to explain how the relationship which has been interfered with by human activities and later rehabilitated may recover.

Studies have established that riparian vegetation could provide organic inputs, such as woody debris and leaf litter, to the stream ecosystem (Newham, Fellows, & Sheldon, 2011). The woody debris creates a habitat and provides nutrients to stream organisms, dissipates energy and traps moving materials (Naiman & Decamps, 1997; Sheldon, Boulton, & Puckridge, 2002; Xu & Liu, 2014) while it also stabilize the stream channel (Talmage, Perry, & Goldstein, 2002). Furthermore, woody debris may influence macroinvertebrate diversity (Johnson et al, 2003) due to the fact that macroinvertebrates find refuge and stable substrate for their colonization following flow disturbances (Hax & Golladay, 1998; Hrodey, Sutton, Frimpong, & Simon, 2009;Tiago, Marcia, Carla, & Maria, 2015). These studies explain in detail how removal of vegetation from the catchment may affect stream materials and thus affect river health. However, the ecological impact of converting forested riparian zone into agricultural land remains unclear especially on aquatic macroinvertebrates assemblages in streams originally forested and then converted into agriculture as occurs in much part of the Kuywa.

Streams that drain preserved areas in tropical and subtropical regions maintain high diversity of aquatic macroinvertebrates (Crisci-Bispo, Bispo, & Froehlich, 2007; Melo & Froehlich, 2001; Siegloch, Froehlich, & Spies, 2012). It has been observed that streams with good riparian vegetation cover have higher species richness than streams without such vegetation (Corbi & Trivinho-Strixino, 2008). For instance, land uses in annual crops, such as sugarcane and pasture, which is the case of lower parts of Kuywa, cause different impacts on the chemical composition and communities of aquatic macroinvertebrates living in streams (Ometo et al., 2000; Suriano, Fonseca-Gessner, Roque, and Froehlich, 2011). Studies in tropical streams have documented a decrease in richness of aquatic insects of the orders Ephemeroptera, Plecoptera and Tricoptera (EPT) in streams impacted by land uses (Hepp, Milesi, Biasi, & Restello, 2010; Hepp & Santos, 2009; Nessimian et al., 2008; Salvarrey, Kotzian, Spies, & Braun, 2014; Siegloch, Suriano, Spies, & Fonseca-Gessner, 2014). These three orders are considered the group of aquatic insects most sensitive to human interference (Rosenberg & Resh, 1993). These studies on sensitive orders have been studies outside the equatorial region. Furthermore, non of these studies have been carried out on the Kuywa River to establish how it relates to other streams.

Generally, an important connection exists between natural terrestrial and aquatic environments (Kennedy & Turner, 2011). This is due to the fact that riparian zones support a unique assemblage of species as compared to upland areas (Sabo et al., 2005). One of the most important lateral subsidies which support aquatic macroinvertebrates from the riparian vegetation is the form of nutrients and energy (Baxter, Fausch, & Saunders, 2005). At this point it should be noted that subsidies are two-way, moving from aquatic to terrestrial systems and vice versa (Kennedy & Turner, 2011). However, it should be noted that it is not only the aquatic fauna which benefits from material and energy movement as they also increase the abundance and species richness of riparian predators, such as spiders, predaceous beetles, lizards and birds (Burdon & Harding, 2008; Kato, Iwata, Nakano, & Kishi, 2003). Similarly, terrestrial inputs to aquatic systems have proved to be important subsidies that positively influence the population of stream fauna (Kawaguch, Taniguchi, & Nakano, 2003). This relationship has been conceptualised by Cummins (1974) (Figure 1). Therefore, removing riparian zone forests could alter aquatic food web dynamics by increasing available light and stimulating benthic algal production, while at the same time reducing leaf litter inputs, including nutrients, to streams (Neil et al., 2012) (Figure 1).

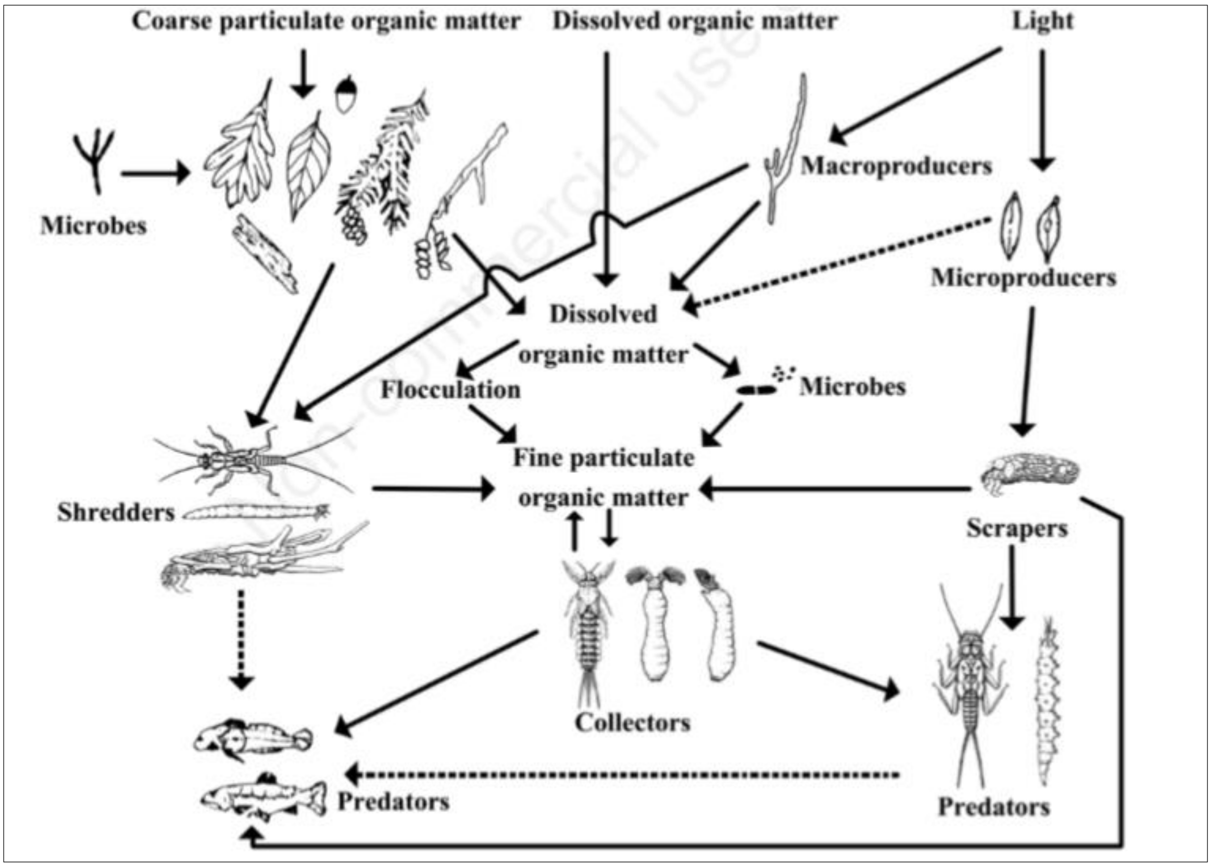


Figure 1: Stream ecosystem conceptual model of energy sources and transfers through the macroinvertebrate community. On the right, the energy of sunlight drives in-stream primary production (algae and rooted vascular aquatic plants) that is utilized by scrapers. On the left, the energy source is the input of plant tissue (CPOM) from the riparian zone and utilized by shredders once it is conditioned by hyphomycete fungi and bacteria. Shredders convert this coarse plant tissue to FPOM that is transferred to collectors. Predators feed on all FFGs (from (Cummins, 1974).

Many countries have a long history of using macroinvertebrates to monitor the ecological status of river health (Hellawell, 1986), and they link it to the natural riparian vegetation cover (Wallace & Webster, 1996). This is because for many year benthic macroinvertebrates have been considered as the key component of aquatic food webs that link organic matter and nutrient resources (e.g., leaf litter, algae and detritus) with higher trophic levels (Wallace & Webster, 1996). Since these organisms have mostly sedentary habits (Li, Zheng, & Liu, 2010) their assemblage characteristics represent specific ecological conditions in a given river stretch. Threfore changes in riparian vegetation cover would likely affect them more especially during the sensitive life stage (Hutchinson, Solbe, & Kloepper-Sams, 1998) which finally affect their assemblage attributes since they have relatively long life span (Li et al., 2010). With these facts only a few studies have been undertaken to investigate how the planted riparian vegetation may affect the functioning of aquatic macrioinvertebrates (e.g. Sheldon et al., 2002; Parkyn et al., 2003; Zhao et al., 2013) and more so all are in temperate regions. Minimal studies have been carried out to investigate the response of macroinvertebrate assemblages to planted riparian vegetation and how it compares with the findings of the natural riparian.

The condition of vegetation cover either to cover or expose the river to other disturbances such as cattle grazing has been found to affect the macroinvertebrate assemblages (Sheldon & Walker, 1998). Sabo et al. (2005) established that changes in riparian forest age, canopy structure and plant communities may modify the composition of stream communities and functional roles played at community levels. However, limited studies have been undertaken in African rivers how the riparian vegetation provide both physical and biological variables to determine river health (e. g. Masese, Muchiri, & Raburu, 2009; Odume, Muller, Arimoro, & Palmer, 2012; Orwa, Raburu, Ngodhe, & Kipkorir, 2014). Furthermore, no study has been undertaken on the Kuywa River where land use has been changed to grazong, intensive agriculture and sugarcane plantations.

In Africa, the concept of stream restoration by planting riverine vegetation is new (Odume et al., 2012; Raburu et al., 2009). The South African River Health Monitoring Program investigates the macroinvertebrate assemblages in different rivers under different disturbance gradients (Nojiyeza, 2013). Both in Uganda and Tanzania, the Lake Victoria Environmental Management Progragram investigated the characteristics of macroinvertebrate and microinvertebrates assemblages in Lake Victoria and its rivers in natural and disturbed gradients (Njiru et al., 2008). Further, studies have been carried out in upland rivers of the Usambara Mountains of Tanzania to evaluate the impacts of tea plantations in the catchment of rivers on macroinvertebrates assemblage (Biervliet, 2009). These previous studies in Africa focused on disturbances on natural river vegetation and their impact on macroinvertebrates. However, no study has been carried out to investigate the influence of planted riparian vegetation cover on benthic macroinvertebrate assemblages attributes.

In Kenya, a number of studies have been undertaken by using macroinvertebrates as an indicator of river health (e.g. Masese et al., 2014; Orwa et al., 2013; Raburu et al., 2009). In the Mara River physico-chemical water quality parameters under different land have been investigated and how they affect spatial distribution of benthic macroinvertebrates (Kilonzo et al., 2014; Minaya, MClain, Moog, Omengo, & Singer, 2013). Further, in the Mara River classification of shredder using gut contents has been carried out at different pollution gradients (Masese et al., 2013). In the Njoro River, Makoba, Shivoga, Muchiri, and Miller (2008) investigated the influence of seasonality and point source effluent pollution on the water chemistry and the structure of benthic invertebrate. On the other hand, Raburu, Masese, and Mulanda (2009) developed a macroinvertebrate Index of Biotic Integrity for monitoring rivers in the upper catchments of Nyando and Nzoia Rivers. Furthermore, Ndaruga, Ndiritu, Gichuki, and Wamich (2004) established the relationship between water quality parameters and macroinvertebrate assemblages in Getharaini drainage in central Kenya. All these studies focuse on the enfluence of land use on benthic macroinvertebrates. None of these studies has documented the influence of riparian vegetation cover on benthic macroinvertebrate composition.

2.4 Temporal variation of water quality parameters and benthic macroinvertebrate assemblage characteristics

Macroinvertebrates integrate acute and/or chronic changes in physical, chemical and biological components of their environment (Plafkin, Barbour, Porter, Gross, & Hughes, 1989). Programs that are based on long-term monitoring are useful in identifying trends in biological measurements as well as nonspecific water quality (Bruce, 2002). Fitzpatrick and Giddings (1997) have also suggested that complimentary habitat analysis is useful in furthering understanding of the interactions among chemical, physical and biological characteristics. When habitat quality among sites is similar, differences in macroinvertebrate communities and measures of these communities can be attributed to water quality factors (Bruce, 2002). But when the habitat quality differ, evaluation of the habitat is necessary to determine the magnitude that habitat may be a limiting factor in macroinvertebrate structure (Bruce, 2002). As indicated in this literature, land use changes is a key factor in determining the habitat quality. Like in other watersheds, Kuywa River watershed could be having increased storm runoff over short period of time and alter baseflow characteristics which might be detrimental to the macroinvertebrate assemblages. Despite this there is no information about the aquatic macroinvertebrate or habitat condition of the Kuywa River that has been compiled, analysed or published.

Excessive water quality parameters can cause long or short-term shifts in macroinvertebrate community richness, abundance and species composition (Aura, Raburu, & Jan Herrmann, 2011). Some physical variables such as altitude do not change with change in season while others such as stream width, and discharge changes between dry and wet seasons (Sanchez-Arguello, Cornejo, Pearson, & Boyero, 2010). Stream width which co-varies with altitude has also been found to vary with season, wet season being wider than the dry season (Sanchez-Arguello et al., 2010). When interpreting water quality parameters and their influence on macroinvertebrate assemblages, care should be taken since even canopy cover, alkalinity and dissolved solids sometimes are related to altitude, although they are frequently related to human activities (Allan, 2004). But generally, most studies indicate more macroinvertebrate densities and taxonomic richness to be higher for the dry season than wet season (Masese et al., 2009; Sanchez-Arguello et al., 2010). On the other hand variation densities and richness among sites during the wet seasons are less obvious due to the dilution effect caused by the increased discharge (Ramirez & Pringle, 2001). Seasonal variations in water depth, current velocity and turbidity may affect macroinvertebrate assemblages and their trends are important in investigating river health. To date there is no baseline database for such changes in Kuywa River.

Increased nutrient organic matter or contaminant concentration in surface water, sediments of food sources has been shown to result in the abundance of stress tolerant species (Sarkar, Bhattacharya, Debnath, Bandopathaya, & Giri, 2002). As argued by Aura et al. (2011), it is not clear whether the relationship between the number of macroinvertebrate species and the amount of nutrient available is positive or negative at a particular stream. On the other hand, Herrmann (1999) and Lewis, Klemm, and Thoeny (2001) argue that slight eutrophication seem to favour increased macroinvertebrate diversity in a long term basis.

Previous studies suggest that water quality parameters are essential for macroinvertebrate diversity which is an indicator of river health (Belsky et al., 1999; Sarkar et al., 2002). Other studies (Aura et al., 2011; Herrmann, 1999; Lewis et al., 2001) argue that there is a relationship between macroinvertebrates and nutrient levels in the river. However, as argued by Kilonzo et al. (2014), sites which are located close to forested area have lower temporal variations in water quality parameters compared to those sites located in the agricultural and densely populated areas. But it is common to find some sites near the forest having direct anthropogenic impacts, especially caused by large numbers of livestock that drink directly in the river (Kilonzo et al., 2014). The data to examine the exact extent of temporal changes in water quality parameters may not be accurate due to inability to exactly capture the peak nutrient fluxes when one uses manual sampling equipment (Kilonzo et al. 2014; Schwarz, Hoos, Alexander, & Smith, 2006). Furthermore, most of the literature on evaluation of river restorations are based on a single snapshot that may not accurately capture the response of the restored reach (Buchanan, Nagle, & Walter, 2014). Therefore, previous studies have a limitation in the knowledge of temporal lag in chemical transport and their causes which create uncertainties in the periods over which steady-state condition apply. Lack of empirical data to back these interrelationships led to the knowledge gap in understanding riparian vegetation cover-macroinvertebrate-river health nexus for the Kuywa River.

2.5 Policy, Legislation and institutional Framework for the riparian zone conservation.

2.5.1 International and National policies

Conservation of riverine riparian zone by provision of desired vegetation is included in the operationalization of Integrated Water Resource Management (IWRM) principles (Ballweber, 1995; Mitchell, 1990). IWRM is widely accepted in many parts of the world, including European Union Water Framework directive (Hedelin, 2007) and Africa water vision plan under NEPAD initiative (Mutua, 2008).

In Kenya, the issues of water resource management has been incorporated in the constitution of Kenya, 2010 under chapter five which is Land and Environment. Section 42(a) states that ‘every person has the right to a clean and healthy environment (RoK, 2010). This section 42(a) includes the right to have the environment protected for the benefit of present and future generations through legislative and other measures’. Section 43(1) (d) states that ‘every person has the right to clean and safe water in adequate quantities. Section 60(1) (c) (e) states that

‘Land in Kenya shall be held, used and managed in a manner that is Productive and sustainable, and in accordance with among others the principles of Sustainable and productive management of land resources and sound conservation and protection of ecologically sensitive areas’. Section 66(1) states that ‘the State may regulate the use of any land, or any interest in or right over any land, in the interest of public health, or land use planning’. Section 66(1) (a) (b) (c) (d) states that ‘the State shall ensure sustainable exploitation, utilization, management and conservation of the environment and natural resources, and ensure the equitable sharing of the accruing benefits; work to achieve and maintain a tree cover of at least ten per cent of the land area of Kenya; protect and enhance intellectual property in, and indigenous knowledge of, biodiversity and the genetic resources of the communities; and encourage public participation in the management, protection and conservation of the environment’. Section 66 (2) emphasizes that every person has a duty to cooperate with State organs and other persons to protect and conserve the environment and ensure ecologically sustainable development and use of natural resources.

2.5.2 Legislation and Institutional Framework

Every water resource in Kenya is vested in and held by the national government in trust for the people of Kenya (RoK, 2016). The Water Resources Authority (WRA) serve as an agent of the national government and regulate the management and use of water resources (RoK, 2016). In order to operationalize the IWRM at the grassroots level, the Water Act 2016 establishes the conditions for establishment and functions of Water Resource Users Association (WRUA). Section 29 (1) (2) indicates the necessity of WRUAs at sub-basin level and indicates that it shall be a community based association for collaborative management of water resources and resolution of conflict concerning the use of water resources (RoK, 2016). The Water Act 2016 provides for creation of fundamental institutions for participation in riparian zone management through the land owners association, however fails to stipulate clearly the institutional structures for inter-agency cooperation and mechanisms for dealing with power disparities. Nevertheless, it provides a window for the WRA together with the community to come up with the basin water resource management strategy which should come up with detailed mechanisms for water resource management (RoK, 2016).

2.5.3 Water Resource Users Association in Kuywa River

The concept of WRUA is relatively new in Kenya. According to the Water Act 2002, the WRUAs represent community based organizations that come together around a specific water resource for cooperative management and conflict resolution (RoK, 2002). From the existing literature the WRUA concept has evolved from notable experiences of both the Water Users Associations (WUA) and from community interest groups in general prior to the water act 2002. These WUAs were made up of persons who come together to develop water supply project for their members. Generally as defined by Ako, Eyong, & Nkeng (2010), a water user association is a non-profit organization that is initiated and managed by a group of water users along or around one or more hydrological sub-systems.

Since the operationalization of the Water Act 2002, there has been a rapid development in Kenya toward the establishment of WRUAs as a vehicle for mobilizing stakeholders to take an active and inclusive participation in the sub-catchment management issues like managing conflicts, monitoring water use and undertaking catchment conservation (Ludeki, 2006). Studies show that, first, WRUAs will enable water users to have a direct stake in the water resources management (Ludeki, 2006). Second, water resource management works best in environment of cooperation (Ludeki, 2006). Third, water resource users have more local knowledge on water-related issues (Ludeki, 2006). Fourth, water users are more likely to comply if they are involved in developing the rules that constrain them (Ludeki, 2006). And lastly, water users are more likely to mobilize local resources if they can see tangible results (Ludeki, 2006).

The main functions and objectives of a WRUA among others are: Promote good management practices to make efficient and sustainable use of the water resource; Promote water conservation practices to ensure sufficient water reserves to meet the demands of the environment, the wildlife, the livestock and all the communities who rely on the water resource; and Promote catchment conservation measures to improve water quantities and quality (RoK, 2016).

2.6 Conceptual Framework

The conceptual framework (Figure 2) defines two independent variables (Water quality parameters and riparian buffer vegetation cover) and one dependent variable (Aquatic macroinvertebrate assemblage variables). Water quality parameters which include both physical and water chemistry parameters are hypothesized to influence the structure of benthic macroinvertebrates in a river system. At the same time, riparian buffer vegetation cover is also hypothesized to determine the structure of benthic macroinvertebrates. In a naturally conserved healthy river system, there is a delicate balance between abiotic (physico-chemical) and biotic (living) characteristics of the environment (Cummins, 1974). Any perturbation to either of the two factors undoubtedly destabilize the equilibrium leading to negative impacts to the integrity of the river ecosystem (Xu & Liu, 2014). However, weather variations and other anthropogenic activities not monitored in this research may intervene and change the outcome of aquatic benthic macroinvertebrate assemblage variables. For instance, high stream discharge bring more sand into the river which encourage sand harvesting leading to disturbed habitat for aquatic benthic macroinvertebrates. Furthermore, government regulations may either encourage the establishment of conducive river environment or discourage it. The Kenya Water

Act 2016 requires that measures be developed for the protection, conservation, control and management of water resources and guidelines/Regulations for approved land use for the riparian area (Water Act, 2016). The Water Act 2016 requires that water bodies be regulated and protected from adverse impacts (water quality and pollution control aspects). The government regulations thus lead to definition of activities to be undertaken in rivers and riparian areas including the establishment of riparian vegetation cover.

Ephemeroptera, Plecoptera and Trichoptera metrics are widely used as part of multimetric indices (e.g. Collier, 2008; Stoddard, Larsen, Hawkins, Johnson, & Norris, 2006) or in isolation for assessing responses of streams to a wide range of stressors, including forest harvesting (Collier & Smith, 2005), nutrient runoff (Hering et al., 2006), as well as modification to riparian and catchment land cover (Sponseller et al., 2001). Accordingly, it has been included in the development of macroinvertebrate indices for Kuywa where it is anticipated to respond to changes in riparian vegetation cover.

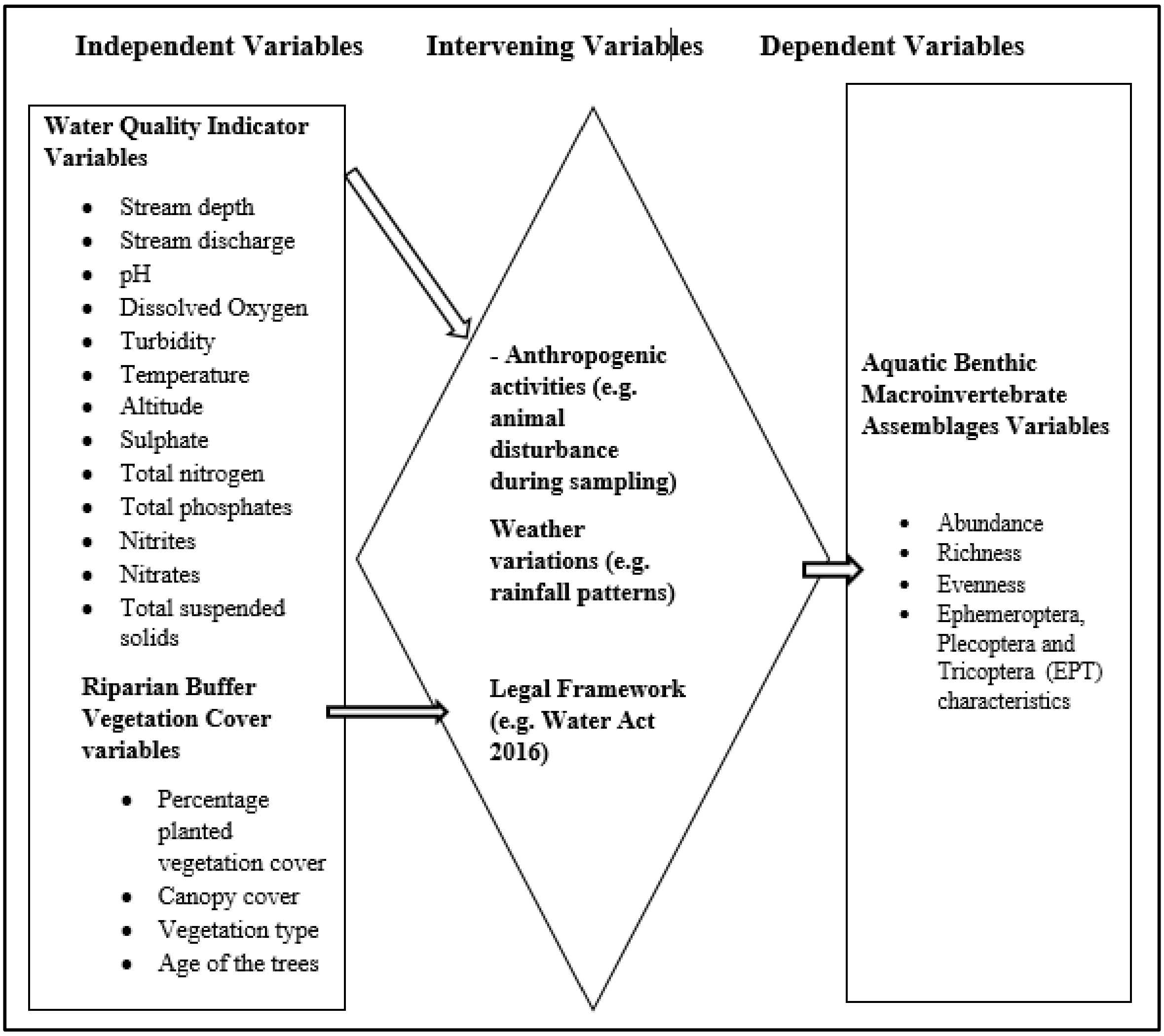


Figure 2: Conceptual Framework for the relationship between water quality parameters and riparian vegetation cover and aquatic benthic macroinvertebrate parameters.

Source: Researcher, 2015

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter provides a detailed account of the methodological procedures used in this study. First, the area under study is described and how it relates to the river health, then secondly, the research methodology and design used in carrying out this research is outlined. Third, sampling and data collection techniques are discussed. Finally, data analysis procedures are presented.

3.2 Study Area

3.2.1 Location and Size:

The Kuywa catchment is bounded by latitude 034º 32` 53” E and 34º 45’ 32” E and 0º 25’ 24” N and 1º 50’ 40” N. The entire river system is approximately 110km long. It originates from Mt. Elgon forest and discharges its waters into Nzoia River at Khalala, a major river draining into Lake Victoria (RoK, 1984). Lake Victoria is the source of Nile River and serves as source of water to Uganda, Sudan, and Egypt before it drains into Mediterranean Sea. Thus the health of Lake Victoria Rivers is of great importance to these downstream countries apart from its importance to the lake residents. The area of study is the entire river system, including the tributaries that drain into the Kuywa River, which include the Kibingei, Misikhu, Kibisi, Samita, Chenjeni, Namawanga, Chebukaka, Chebusitati, Sitolola, Bokoli and Ndaret streams which join the Kuywa River at different points (Figure 3).

The Kuywa River drains an estimated area of 580 square km^2. The river originates at the peak of Mt. Elgon at an altitude of 4,200 m above sea level. The lowest part of the river is at Khalala, which has an altitude of 1,505 m above sea level. The Kuywa catchment area slopes southwards, with the upper parts, such as Masaak, Teremi, Emia, Sikulu, Kapkateny, Kapsambo and Nakoyonjo, consisting of steep slopes. The middle parts, which include areas such as Namawanga, Majakha and Kibingei, are gentle sloping, while the lower section of Sitikho, Kongoli and Khalala has even more gentle slopes (RoK, 1984). The upper parts with steep slopes lead to a high velocity of water in both river channels and overland flow, which reduces infiltration into ground water aquifers and, at the same time, accelerates soil erosion. This in turn leads to the high sedimentation of the Kuywa River and its tributaries. Areas cleared of riparian vegetation receive this sediment.

The Kuywa River receives much of its runoff from the springs, which are perennial, and a stable ground water recharge as evidenced by the 13 boreholes and 150 hand-dug wells in the catchment (WRMA, 2011). The river passes through three major swamps, Samita, Namakhele and Namawanga, which function as buffers for flood water during the rainy season and recharge the ground water aquifers (KUWRUA, 2008).

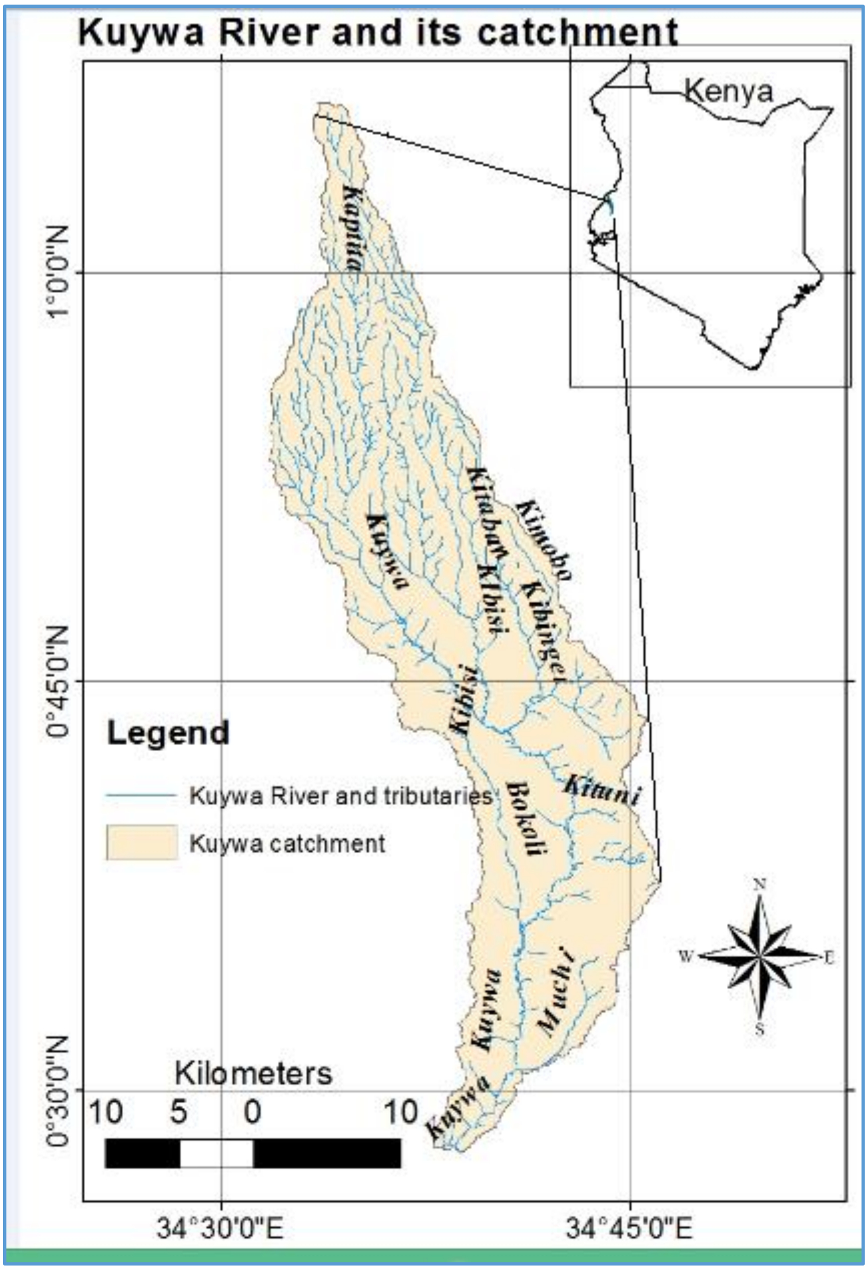


Figure 3: Location of Kuywa River and its tributaries

Source: Researcher, 2017

3.2.2 Kuywa catchment management

The management of the Kuywa River and its tributaries is undertaken by three Water Resource Users Associations (WRUAs): Kuywa Water Resources Users Association (KUWRUA); Teremi Water Resource Users Association (TEWRUA); and Kibingei Water Resource Users Association (KIWRUA) (Figure 3). The KUWRUA was established in 2006 while TEWRUA and KIWRUA were established in 2012. These three community management groups have formulated their own Sub Catchment Management Plans (SCMPs), which stipulate the projects that will be undertaken in the short and long term in order to achieve their aim of improving the health of the Kuywa River. SCMPs are a response to the WRMAs' Catchment Management Strategy (CMS) prepared for the Lake Victoria North Catchment Area (LVNCA) for management, use, development, conservation, protection and control of water resources. The CMS emphasizes Integrated Water Resources Management (IWRM) as the best option for water resource management, which involves all stakeholders in water resources management activities (WRMA, 2007).

The goals of KUWRUA, TEWRUA and KIWRUA are to have a sustainable, environmentally and socio-economically healthy watershed that benefits the communities within and beyond the Kuywa River (KUWRUA, 2008). The first phase of Kuywa River management was to be evaluated in 2011 (5 years). However, to date, evaluation has not been undertaken due to uncertainties of what a healthy river entails. The indicators in the SCMPs give criteria for evaluating project implementation but fail to give criteria for project effectiveness. The proposed study intends to investigate the influence of planted riparian buffer vegetation on improving the health of the Kuywa River.

3.2.3 Population

As of 2009, the population of Kuywa watershed was estimated at 462,961 people with a density of about 550 persons per km^2. This population density, which is mostly dependent on commercial and substance farming, has put pressure on the land to produce food for the population and to be a source of income. Due to the shortage of land, farming in the watershed involves the use of fertilizers and pesticides, which are washed into the river during the rainy periods.

Crops grown in the watershed include maize, beans, kale, Irish potatoes and sugarcane. Kale, potatoes, maize, beans, tomatoes and onions are grown in the wetlands. The demography of the watershed is also influenced by the growing of market centres such as Kuywa and Chebukaka (KUWRUA, 2008).

3.2.4 Climate

The rainfall pattern of the Kuywa watershed is bimodal, and the mean annual rainfall ranges between 250mm in the dry season (from December to February) and 1800mm in the rainy season (from March to May). The catchment experiences a mean annual temperature range of 15° C at night and 30° C in the day (WRMA, 2007). During the long rainy season, the stream flow is usually very high, and the river discharge reaches beyond 17 cubic meters per second at Matisi (WRMA, 2010). Such discharge leads to the flooding of farms, such as the one of 1998 at Namawanga and Matisi. During the flooding, farms are washed away and heavy sediments carried from the Kuywa watershed. The dry season renders the soil more susceptible to erosion by both wind and water.

3.2.5 Geology and Soils

The geology of the area comprises metamorphic rocks having a strike of East–West and dipping in the north. These rocks are coarse-grained foliated gneisses. In some areas, they are covered by young black volcanic soils and ironstones from Mt Elgon Eruptions (Batjes & Gicheru, 2004). These soils and ironstones are from weathering volcanic rocks formed during

Mt. Elgon volcanic eruptions and are depth and well drained. The deep and well drained soils have attracted various farming practices including mixed farming, plantation farming and horticulture along the river and streams. These agricultural activities are sources of sediment into the river, and the organic fertilizers used may end up in Kuywa River affecting the river health.

3.2.6 Socio-economic activities

The main socio-economic activities in the catchment comprise subsistence and commercial farming (KUWRUA, 2008). Commercial farming mainly involves the growing of sugarcane, coffee, potatoes, bananas, and horticultural crops. Sugarcane is grown at the lower parts of the Kuywa River; that is, around Matisi, Kongoli, Mwibale, Khalumuli, Bokoli, Khalala, Sikalame, Milo, Bukunjangabo, Sitikho, Malaha and Mangana (Figure 4). Coffee farming is mainly carried out in high altitude, which comprises areas such as Kimorong, Kapkateny, Kapsambo, Nakoyonjo, Mukuyuni, Kimalewa, Chebukaka and Teremi. Potatoes and bananas are grown all over the watershed, while horticultural crops are mostly located in areas bordering the conserved forest, especially around Kimalewa, Kapkateny, Teremi and Kuywa market (Figure 4). Horticultural crops that mature within a short period, such as potatoes, tomatoes and onions (which only take three months), leave the soil uncovered for most part of the year. This makes the soil susceptible to erosion during the rainy season, thus reducing soil fertility on farms and increasing sedimentation of the Kuywa River. If not well managed, the pesticides, herbicides and fertilizers, such as phosphorus and nitrates, used in sugarcane, coffee and horticulture farms end up deteriorating the quality of water from the watershed to the river (KUWRUA, 2008). The main subsistence crops in the Kuywa watershed include maize, cassava and beans. The harvested fields of these subsistence crops are often grazed by cattle while waiting for the next season. Grazing of cattle, especially during the dry period, loosens the soil and makes it susceptible for erosion during the wet season.

The introduction of the *Eucalyptus* species along the Kuywa River riparian reduces the undergrowth vegetation thus minimizing the allochthonous materials into the stream (Kenya Forest Service, 2009). Allochthonous materials are one of the main sources of carbon flux into the aquatic ecosystems. The undergrowth also filters the contaminants from the runoff before reaching the stream.

3.3 Research design

This study was conducted through empirical cross-section descriptive research design. The design is concerned with establishing the influence of riparian buffer vegetation cover and water quality parameters on benthic macroinvertebrates in the Kuywa River. A cross-sectional study design was used in examining the relationship between water quality parameters and riparian vegetation cover on benthic macroinvertebrate assemblage characteristics at the selected nine sites over a period of one year. The research was based on observed and measured phenomena and derived knowledge from actual measurements rather than from theory or belief (Bryman, 2012). It was specifically intended to establish the current situation of the relationship between variables in Kuywa River. Cross-sectional design was used to collect both water quality parameters and macroinvertebrate data at a single point over different seasons of a year to detect patterns of association (Bryman, 2012).

It also employed longitudinal design for the purpose of comparing seasonally independent variable (planted riparian vegetation cover and water quality parameters) and dependent variables (benthic macroinvertebrates characteristics). The design enabled the researcher to explain how seasonal variations in water quality parameters and planted riparian vegetation cover varied with benthic macroinvertebrate assemblages in the Kuywa River.

The units of analyses for the purpose of this study was water in the Kuywa River and riparian vegetation cover along the Kuywa River.

3.4 Study Population and Sampling

The sample sites were chosen along the Kuywa River for research purposes (Figure 4 and Table 1). The criteria and technique for choosing the sampling sites are discussed below.

Table 1: The spatial distribution for the sample sites and their location in longitude (Long) and Latitude (Lat.) and altitude (Alt) as well as physical attributes (Land use, local watershed erosion and category) during the study period.

Station (sample site)	Latitude	Longitude	Alt (M)	Land-use	Category of riparian vegetation
A	0.58395	34.6908	1440	Sugar cane plantation	Sugar cane plantation
KG	0.73628	34.68845	1534	Agricultural, eucalyptus bank vegetation	Planted eucalyptus
KS	0.75534	34.65931	1533	Agricultural	Natural conserved
K1	0.75068	34.6403	1548	Agricultural	Planted mature
K2	0.78208	34.6121	1574	Agricultural, open grazing	Planted mature
T1	0.81716	34.58682	1956	Grazing	Recently fenced and retired from grazing
E	0.82473	34.58234	1970	Agricultural	Planted young
T2	0.8244	34.58379	1960	Agricultural	Planted mature
KM	0.8873	34.58733	2304	Forest, open grazing	Natural conserved

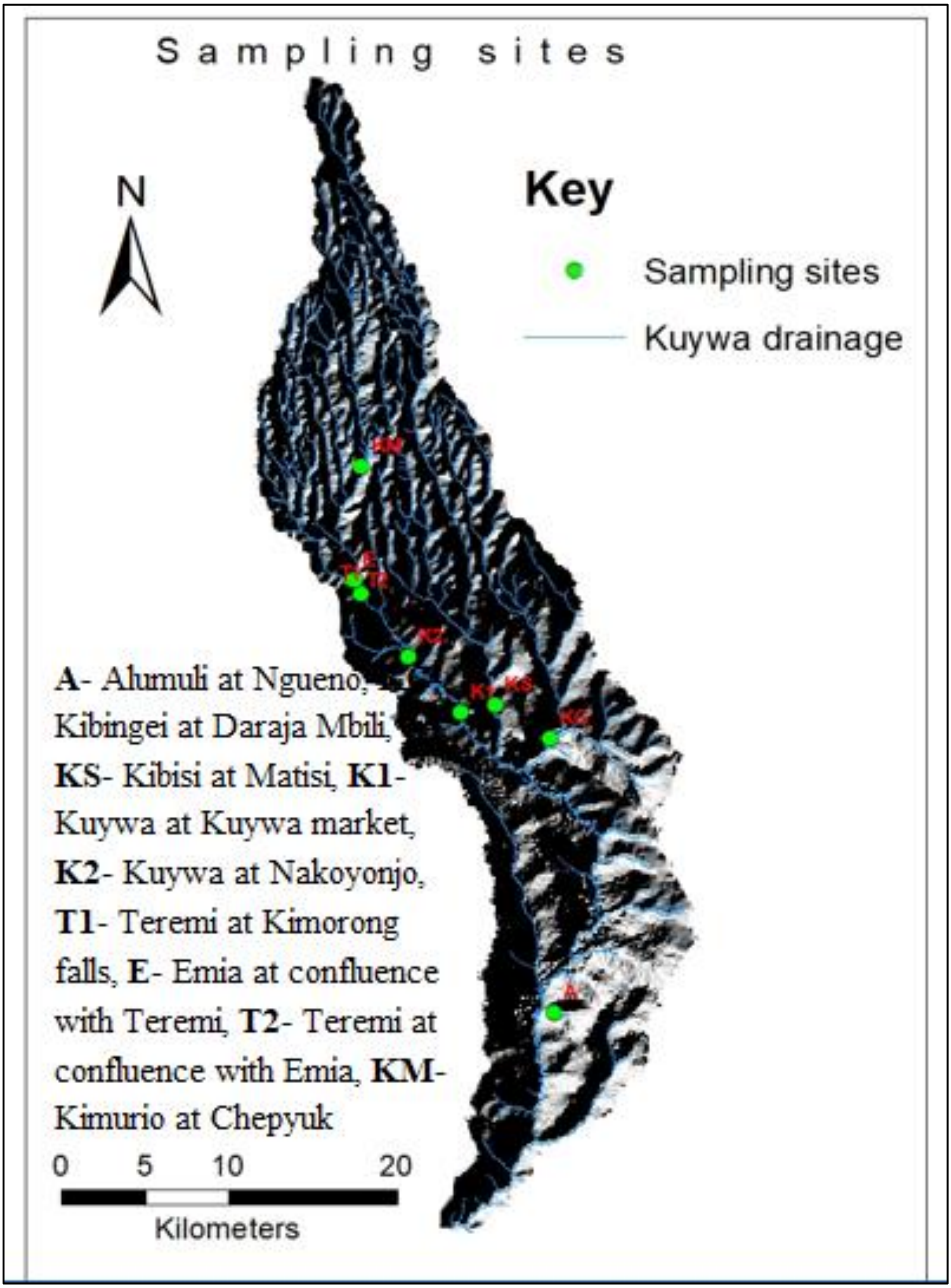


Figure 4: Sampling sites on Kuywa River and its tributaries

Source: Researcher, 2017

Nine sampling sites were identified in the Kuywa River basin, which represented a range of planted riparian vegetation cover and were spatially separated to cover as much of the catchment as possible. Nine sites were considered adequate since most of the previous studies on the related subject considers four to ten sites as adequate. Liu et al (2016) studying assessing ecological health of the Yellow River selected 4 sites. Makoba et al. (2008) investigating the use of benthic macroinvertebrate indicators of water quality in Njoro River selected 10 sites. Aura et al. (2011) studying macroinvertebrate's community structure in Kipkaren River and Sosiani River selected seven sites. Sites chosen were those rehabilitated or have been retired from grazing for at least two years. Each site that has been rehabilitated by re-vegetating or fencing off (to eliminate grazing) the buffer zone was compared with an un-vegetated or actively grazed riparian zone. Since the extent of the buffer zone may influence the stream properties, a 100m distance from the sampling site upstream were surveyed at each paired site and physical-chemical and biological parameters measured. Of these nine sampling sites, one site (KM) with near-natural riparian condition (Barbour & Stribling, 1993; Raven, Fox, Everard, Holmes, & Dawson, 1997) was chosen to be control or reference site, while another site (A) which was degraded by planting sugar cane up to the riparian served as the second control site. The remaining seven sampling sites with a re-vegetated riparian buffer zone were test or study sites. Control sites provided reference standard to which the study sites were compared (Jungwirth, Muhar, & Schmutz, 2002). The sampling of these nine sites was carried out between January and October, 2016. This ensured that both the rainy and dry periods were captured so as to investigate both the spatial and temporal effectiveness of the planted riparian buffer vegetation.

3.5 Description of the sampling sites

The nine sites where sampling was undertaken photos were taken photos clarity of their description in terms of riparian vegetation characteristics and they are given in plate 1-9.

<u>Site A – Alumuli at Ngueno</u>

Plate 1: Alumuli at Ngueno

This is located at a small tributary which drains into the Kuywa River. Visually, the stream carries minimal sediments. It traverses sugarcane nuclear plantation for Nzoia Sugar Company. The riparian is well covered by natural vegetation including tall grass. However, the sugarcane is planted in some sections up to the river bank. The vicinity is the sugarcane planted behind the riparian vegetation.

Site KG – Kibingei at Daraja Mbili

Plate 2: Kibingei at Daraja Mbili

This site is on Kibingei tributary just before it drains into Kuywa River. The site is planted with eucalyptus trees on either side of the river. Very little shrubs and grass has regenerated as undergrowth. The side has got regular disturbance upstream by cattle as it is used as watering point. During the rainy season the site is used for harvesting sand.

Site KS – Kibisi at Matisi

Plate 3: Kibisi at Matisi

This site is located on Kibisi stream before it drains into Kuywa River. The site riparian vegetation has been conserved by the community and appears to be intact. However the surrounding land use comprises of intensive agriculture. There is no noticeable disturbance to the river within 100m upstream and downstream.

Site K1 – Kuywa at Kuywa Market

Plate 4: Kuywa at Kuywa Market

This site lies in the main Kuywa River. This section of the river has been rehabilitated by planting indigenous vegetation on the river bank. The planted vegetation is mature and well maintained to resemble natural vegetation. The canopy has covered a great portion of the river section. No animal disturbance is at this site, however, some sections of the riparian has been cleared of vegetation about 150m upstream of the sampling point.

Site K2 – Kuywa at Nakoyonjo

Plate 5: Kuywa at Nakoyonjo

This site is located in the main Kuywa River. This site has got one bank (right) being a grazing field, while the other (left) planted with riparian vegetation which is mature. About 100m upstream of the sampling site, one the right bank is riparian vegetation while on the left bank is the heavy grazing field. The site appear to have disturbance from human activities especially bathing and washing of clothes in the river. However, at the sampling point disturbance was minimal.

Site T1 – Teremi at Kimorong falls

Plate 6: Teremi at Kimorong falls

This site is located at the main Kuywa River, however it is called Teremi due to differences in ethnicity. It is about 20m upstream of Kimorong falls. The riparian zone has been fenced off so that it can regenerate, however there were signs of recent grazing taking place. By the time sampling was being undertaken for final data (October, 2016), construction of hydro-power had started about 20m downstream, which made sampling site to move 50m upstream.

Site E – Emia at confluence with Teremi

Plate 7: Emia at confluence with Teremi stream

This site is on Emia stream which is a major tributary of the Kuywa River. The site is about 100m away from the confluence with Teremi (Kuywa) River. The riparian vegetation comprised of young planted indigenous trees and shrubs which have emerged after rehabilitation. Some section within 100m upstream the young trees were intercropped with maize and beans. At the same time within 100m upstream was a riffle forming a small waterfall. There was no indication of animal disturbance at this sampling point.

Site T2 – Teremi at confluence with Emia Stream

Plate 8: Teremi at Emia

This site is at the main Kuywa (Teremi) River, just before Emia tributary joins it. The riparian vegetation comprised of planted mature indigenous trees, but heavily impacted by cattle grazing. Just behind the planted vegetation, the farms are heavily used for horticultural crops such as Kales, Irish potatoes, onions and green peas. The site had indication of some disturbance from animals and human washing in the river.

<u>Site KM – Kimurio at Chepyuk</u>

Plate 9: Kimurio at Chepyuk

This site is located at the main Kuywa River but local name being Kimurio stream. The site is at the upper most part of the river system, just after it leaves Mt. Elgon conserved forest. The site is well conserved of its riparian vegetation being near to natural. However, 100m upstream there was an animal watering point being shared by wild animals and cattle. There was minimal human interference with the river system except for the wild animals.

3.6 Sources and methods of data collection

The procedure is outlined in the Queensland AusRivAs Sampling and Processing Handbook (AustralianGovernment, 2001). This procedure is also comparable to South African Scoring System (SASS) (Thirion, Mox, & Woest, 1995). Dissolved oxygen and conductivity taken just upstream of the sampling point where water was flowing. This is in accordance with the AusRivAs protocol (Australian Government, 2001), which requires all water quality measurements to be carried out upstream of the point where the biological sampling is to be done.

3.6.1 Riparian vegetation cover condition characterization

At each of the nine sites (planted, open and reference sites), the condition of the riparian zone vegetation was observed as per the check list in Appendix 2, visually estimated, photographs taken and recorded for comparison with other sampling sites. The percentage canopy cover was visually estimated and determined over 100m upstream (Masese et al., 2014; Raburu et al., 2009). The average condition of the riparian zone vegetation was considered over the width of 30m from the water's edge on both sides of the river. According to SEPA (2003), Törnblom et al. (2011) and Lazdinis and Angelstam (2005) the width of 30m riparian vegetation condition has an influence on biology of the stream. Therefore, the riparian zone considered included a two-30m wide zones on either side of the stream over a 100 range along the stream. Photographs were taken to cover the 10m sampling distance and to capture the in-stream substrate, canopy cover, and river morphology.

Using riparian vegetation conditions, the indicators for stream health were assessed by adapting (Ladson & White, 1999) methods. The characteristics included were as follows: capacity to filter input, such as light, sediment, and nutrients, to streams; capacity to act as a source of input, such as woody debris and leaves, to streams; and capacity to provide a habitat for terrestrial animals. These characteristics, when broken down into detailed assessment, were found to be numerous, and thus necessitated detailed criteria, which reduced the characterization to four characteristics as shown in Table 2.

To develop a metric for the "riparian condition", a dimensionless rating was given for each indicator based on the proximity each indicator had to the reference condition; a value of 1 was given when the indicator was completely different to what would be expected under the reference condition, and a value of 4 when the indicator was the same (Table 2). The differences in riparian zone conditions for each site can be seen in Plates 1-9.

Table 2: Criteria for riparian vegetation cover classification, description of condition and rating. Adapted from Tornblom et al. (2011) and Aura et al. (2010)

Riparian classification and description of conditions	**Rating**
Excellent No exotic vegetation within 100 m of the riparian zone; natural vegetation intactness > 80%; width of the stream with vegetation > 40%; has more than 90% vegetated bank length within 100 m upstream on both sides	4
Good Exotic vegetation cover within 100m of riparian zone <30%; width of the streamside vegetation 25–40%; longitudinal continuity of indigenous vegetation within 100m upstream 65–80%; structural intactness of the riparian vegetation 60–80% at least on one bank	3
Fair Within 100m exotic vegetation cover 30–60%; width of streamside zone with vegetation 5–25%; longitudinal continuity of indigenous vegetation within 100m upstream 40–65%; and structural intactness of the riparian vegetation 40–60%	2
Poor Within 100m exotic vegetation cover >60%; width of streamside with vegetation <5% (may be characterized by collapsed river banks without vegetation); longitudinal continuity of indigenous vegetation <40%; structural intactness < 40%	1

3.6.2 Physical and chemical variables as well as benthic food materials for each sampling sites

In-situ parameters were measured four times over a period of 10 months, between the months of January to October, 2016 at each station. Sampling was designed so that parameters were measured both in the dry (December–February and June-August) and wet seasons (March–May and September-November). In-situ parameters measured during each sampling event were: subsurface water temperatures, dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids (TDS), pH and flow velocity. These parameters were measured using a portable standardized electronic meter and recorded in a Microsoft Excel spreadsheet for analysis. To get consistent results, the parameters were measured three times and averages obtained.

Stream water quality parameters which include: temperature (T), conductivity (Cond), dissolved oxygen (DO), pH, turbidity, and total dissolved solids were measured in situ using a multiprobe water quality meter manufactured by Hydrolab Company. Total suspended solids (TSS) was measured in the lab using filtration method (APHA, 1998). Sulphates were measured using a turbidity meter through turbidimetric method (applying balium chloride) (APHA, 1998). Phosphorus were measured using spectrophometric method (Ascopic acid) while nitrates (NO_3 -) and nitrites (NO_2 -) were measured using cadium column reduction method then spectrophotometric technology (APHA, 1998). Total phosphorus (TP) and total nitrates (TN) were measured in the laboratory using spectrophotometric method (persulphate) (APHA, 1998). Stream discharge (Q) was measured by wadding method using a FlowTracker Handheld Acoustic Doppler Velocimeter (ADV) manufactured by YSI Environmental Company. The same ADV was used to measure average stream depth, width and average water velocity.

Table 3: Physical and chemical variables as well as Benthic food materials enumerated at each sampling site, units of measurement and the method used for making the measurements.

	Variable	**Units**	**Method**
Physical	Elevation	m	Electronic
	Stream width	m	Wadding
	Stream depth	m	Wadding
	Average velocity	ms^{-1}	Wadding
	Stream temperature	^{0}C	Electronic
	Stream discharge	ms^{-1}	Wadding
Chemical	Nitrate	mgL^{-1}	Iron screening
	Total phosphorus	mgL^{-1}	Ascorbic method
	Alkalinity	mgL^{-1}	Alkalinity meter
	Turbidity	NTU	Turbid meter
	Dissolved oxygen	mgL^{-1}	Dissolved oxygen meter
	TSS	mgL^{-1}	Gravimetric
	Sulphate	mgL^{-1}	Gravimetric
	Electro conductivity	μScm^{-1}	Conductivity meter
	Ortho phosphate	mgL^{-1}	Ascorbic method
	TDN	mgL^{-1}	Copper cadmium reduction
	TN	mgL^{-1}	Copper cadmium reduction
Benthic Food	Wood (debris)		
	Leaves	% (stream bottom coverage)	Visual
	CPOM	% (stream bottom coverage)	Visual
	FPOM	% (stream bottom coverage)	Visual

CPOM: coarse particle organic matter
FPOM: fine particle organic matter

3.6.3 Laboratory physical parameters sampling

This involved those parameters not measured in the field. Samples were taken from the mid-section of the river where there was a good mixing of water either in the run or fall. All water samples were stored in laboratory water sample bottles between 16^{0}c and 20^{0}c during the days of field study and in cool boxes before analysis (Törnblom et al., 2011). The samples were analysed using standardized procedure for nitrates, phosphorus, nitrites, sulphate, total nitrogen and total phosphates.

3.6.4 Benthic macroinvertebrate sampling

From each site, triplicate samples representing microhabitats (such as riffle, pool and run) were taken making a total of 27 samples at one sampling phase. Before sampling at the riffle and run, the debris was disturbed along diagonal transact for five minutes. The benthic macroinvertebrates were sampled using a standardized 250µm mesh dip net. The sampling distance was about 10m. Time taken for each sampling was 60 seconds to produce a representative sample. In the field, collected benthic macroinvertebrate samples were preserved in well labelled polythene bags with a 10% formalin solution and transported to the laboratory. To avoid errors identified by Metzeling, Chessman, Hardwick, & Wong (2003) whereby inexperienced researchers ignore small and cryptic taxa. The benthic macroinvertebrates were identified in the laboratory according to specific procedures (Acũna et al., 2013; Australian Government, 2001; Mathooko, 1998).

In the laboratory, samples were washed using a 250µm sieve and sorted into well labelled plastic bottled containing 70% alcohol. During identification, samples were displayed on a sorting tray and sorted under a stereo dissecting microscope and further preserved in the bottles containing 70% methylated spirit. Samples were identified according to orders, families and genus using standard published and in-house taxonomic identification keys and guides for South Africa, and the abundance of each taxon recorded. Where the identification keys were not sufficient, experts were consulted and identification done. Where some species especially those with numerous taxa could not be sufficiently identifies, classification stopped at the order level.

3.7 Data analyses and Results presentation

To establish the relationship between water quality parameters and benthic macroinvertebrate assemblages in the Kuywa River, inferential statistics were employed. Mean values for the water quality parameters for the eight sites were compared to the control sites. The t-test was used to determine whether there was statistically significant difference between the means in physico-chemical parameters for the eight study sites and the control site KM). Individual benthic species abundance was compared for different sites during the sampling period. To test the hypothesis that water quality parameters did not influence benthic macroinvertebrate species abundance, Spearman rank correlation was used. Further, Spearman's rank correlation was used to test whether water quality parameters has influence on benthic species richness and diversity.

To determine the influence of planted riparian zone vegetation cover on benthic macroinvertebrate species abundance, nine sampling sites were categorized according to the type of vegetation along the riparian zone and then sites classified as 'Poor', 'Good' and 'Excellent'. Spearman's rank correlation was used to show which species had a significant relation with percentage riparian vegetation cover. Spatial characteristics of benthic macroinvertebrate assemblages were obtained by averaging four rounds of field samplings. This was accomplished by employing descriptive statistics which involved computing the species richness Index (S), species abundance index (N), Margalef species richness (d) (Margalef, 1956) (Equation 1), Shannon species index (H) (Maguran, 1988) (Equation 2), Simpson species diversity (λ) (Equation 3) and Pielou species evenness (J) (Equation 4) for benthic macroinvertebrates at different sites. ANOSIM (Analysis of Similarity, 999 permutations) test in the PRIMER software package (Clarke and Gorley, 2006) was used to test the hypothesis that there were no significant difference in abundance between the sites with 'Excellent', 'Good' and 'Poor' vegetation cover. Inferential statistics was also performed to determine Bray-Curtis similarity measure. Further, a SIMPER analysis (Similarity Percentage) was used to estimate the individual contribution and the importance of each species to the global similarity/dissimilarity and consequently the degree of dissimilarity between different sites with different riparian vegetation cover and macroinvertebrate species. The similarity was visualised using Multi-dimensional Scaling (MDS) in Primer v6, (Clarke, Somerfield, & Chapman, 2006) on benthic macroinvertebrates when factored with percentage riparian vegetation cover (Equation 6). Further, the influence of planted riparian zone vegetation on sensitive benthic macroinvertebrate species, Ephemeroptera, Plecoptera and Tricoptera abundance, species richness index and family richness were used.

Margalef: d = $(\boldsymbol{S-1})/\boldsymbol{loge}$N……………. Equation 1

Shannon: H = $\sum \boldsymbol{P_i}\log(\boldsymbol{P_i})$ ………………..…Equation 2   where logs are to the base of e

Simpson: 1-λ = 1-$\{\sum_i \boldsymbol{N_i}(\boldsymbol{N_i}-\mathbf{1})\}/\{\boldsymbol{N}(\boldsymbol{N}-\mathbf{1})\}$…………Equation 3

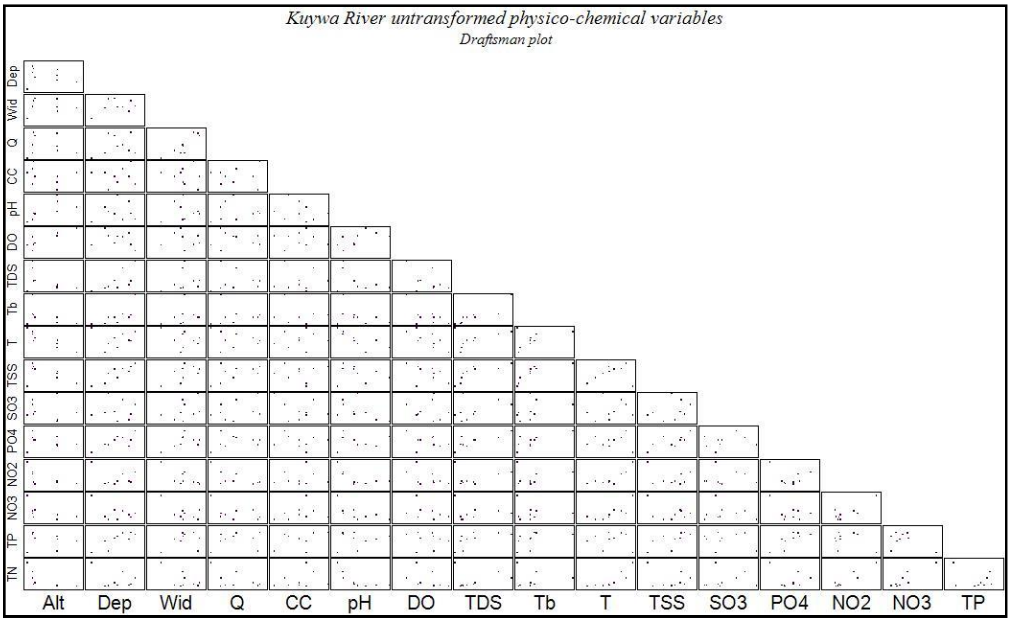
Pielou: J = $\boldsymbol{H}/\boldsymbol{log_e S}$ ………………………………… Equation 4

Where S is total species; N is total individuals; and P_i is N_i/N.

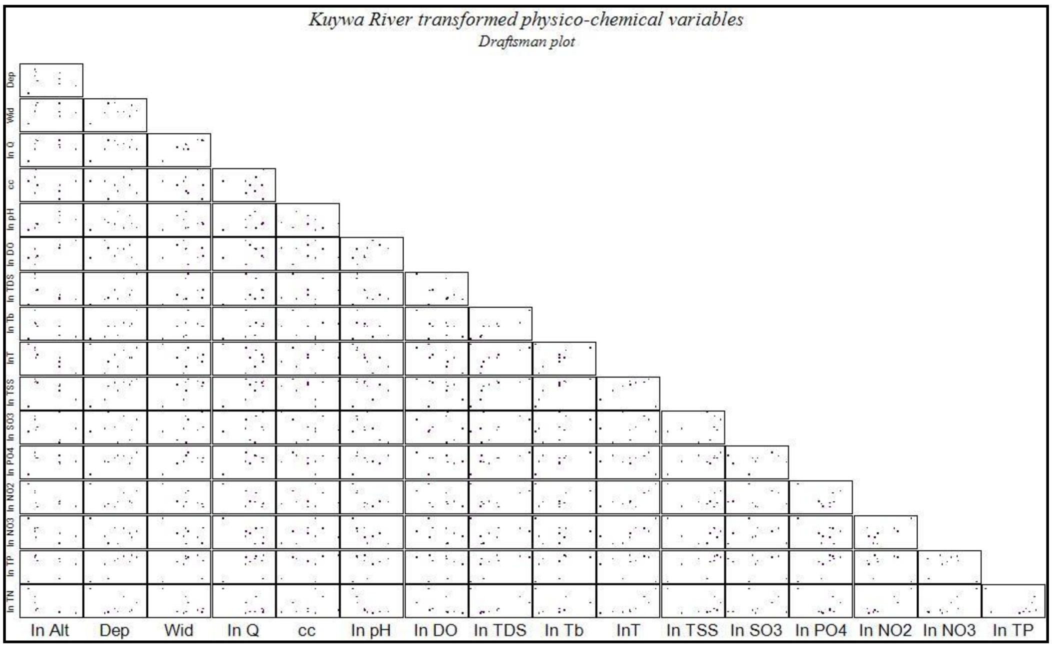
S =100. $\frac{\sum_i \min\{y_{i1}, y_{i2}\}}{(\sum_i y_{i1}+\sum_i y_{i2})/2}$ … … … … … … … … ..Equation 5

Where y_{i1} is the count for the *i*th species from sample 1 and $\sum_i(\ldots)$denotes summation over those species.

To analyse the relationship between temporal water quality parameters and temporal benthic macroinvertebrate assemblage characteristics inferential statistics was used. Principal Component Analysis (PCA) was performed on water quality parameters separately for the two seasons and factored by riparian vegetation condition. However, before PCA was performed, draftsman plots was undertaken to establish which transformation may be necessary on the water quality variables. This was necessary because if the data is strongly skewed the outliers will dominate the PC axes and will lead to poor quality interpretation. Secondly, it was necessary to find out whether there were strong relationships between some pairs of variables which would exhibit linear rather than curvilinear relationship. Figure 5 (a) shows that before transformation most of the variables were skewed to right. After transformation of log(x) the values are more evenly distributed as indicated in Figure 5(b). On macroinvertebrate data, transformation used was square root and log (x).



(A)



(B)

Figure 5: Draftsman plot for water quality parameters. (A) Shows the plot before transformation and (B) after transformation

Log(x) data was standardized (Euclidean distance) and used to generate a distance matrix (Equation 7), which generated a cluster analysis. This was found to be a better method of transforming the data before the application of Euclidean distance similarity, since it down-weighted the importance of highly variable parameters such that the similarity is also accounted for by the less-variable parameters (Clarke & Gorley, 2006).

Pi = $100\frac{\boldsymbol{var(PCi)}}{\sum_i \boldsymbol{var(PCi)}} = 100\frac{\boldsymbol{var(PCi)}}{\sum_i \boldsymbol{var(SPi)}}$ …………………….. Equation 7

Where PCi is the variance of species on the *ith* PC and Var(SPi) is the variance of the points on the *i*th species axis (*i*= 1,2,3).

Graphical trends were used to compare dry and wet seasons for all the water quality parameters. To explain the variance structure for water quality parameters at the nine sampling sites in the dry and wet seasons through linear combinations, Principal Component Analysis (PCA) was used. To determine the influence of seasonality on sensitive benthic macroinvertebrate species, Ephemeroptera, Plecoptera and Tricoptera abundance, species richness index and family richness were used. One-way Analysis of Similarity (ANOSIM) was employed to test for variations between the sampling sites in terms of water quality parameters and measured riparian zone condition for each sampling period. The indirect gradient analysis linking patterns to 'BEST' subsets of water quality parameters to test for matching sample structure (global BEST routine) was performed for each sampling period separately to test the hypothesis. RELATE procedure in Primer v6 was applied to test mull hypothesis that there was no agreement in water quality parameters and benthic macroinvertebrate assemblage pattern.

3.8 Validity and Reliability of the data

3.8.1 Validity

Validity shows how the collected data reflects the investigated concept. For the data collected to be valid its results should respond to the truth and errors minimized (Healy & Perry, 2000; Riege, 2003). The data collection instruments used for this study have been tested in other areas and the published procedures were followed. However, the laboratory equipment employed during the study were calibrated according to manufacturers' specifications.

3.8.2 Reliability

Reliability indicates how replicable or consistent the data results is. Reliable instruments should yield the same results when repeated with the same conditions (Healy & Perry, 2000). This is of particular importance since it determines the constancy and quality of the facts achieved during the study (Riege, 2003). To ensure reliability for this study, each sampling site was sampled three times using the same procedure during the site visits. The primary data collected was subjected to the same analysis parameters to provide accurate comparison.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter deals with the study findings as per the study objectives, then explain the patterns observed, compares with what is known and then highlights the new knowledge the findings have generated. This chapter therefore presents the results from this study under three separate headings so as to accept or reject the above hypotheses: Relationship between water quality parameters and benthic macroinvertebrate species abundance and diversity in the Kuywa River; influence of planted riparian vegetation cover on benthic macroinvertebrate species abundance in the Kuywa River; and the temporal variation of water quality parameters and benthic macroinvertebrate assemblage characteristics in the Kuywa River.

4.2 Water quality parameters and benthic macroinvertebrate species abundance and diversity in the Kuywa River

4.2.1 Water quality parameters

The findings of the study indicated variations of sites in terms of water quality parameters as well as benthic macroinvertebrate species abundance and species diversity. The different water quality parameters were found to be related to benthic macroinvertebrates species abundance and species diversity differently depending whether they were tolerant or intolerant to that particular variable as indicated in Table 4.

Table 4: Mean (± SE) values for water quality parameters at the nine study sites of Kuywa River as measured between January, 2016 and October, 2016

Water quality indicators/Sites	A	KG	KS	K1	K2	T1	E	T2	KM
Altitude (m)	1440	1534	1533	1548	1574	1956	1970	1960	2304
River Depth (m)	0.152±0.03	0.611±0.13	0.482±0.01	0.565±0.04	0.394±0.02	0.331±0.03	0.546±0.07	0.427±0.01	0.296±0.03
River Width (m)	1.85±0.25	5.175±0.26	4.86±0.83	6.45±0.32	7.2±0.47	7.025±0.46	3.75±0.33	4.925±0.50	4.6±0.38
Discharge(M3/sec	0.108±0.03	0.713±0.11	1.659±0.61	3.097±0.96	2.692±0.98	2.975±1.26	0.984±0.40	1.477±0.39	0.688±0.29
% riparian vegetation cover	50	20	60	80	40	5	40	25	50
pH	7.30±0.20	7.40±0.20	7.39±0.09	7.59±0.16	7.58±0.07	7.65±0.18	7.98±0.20	8.20±0.17	7.79±0.24
Electrical conductivity (µS/cm)	60.25±5.69	169±8.45	136±13.37	93.5±7.8	96.75±6.05	74.25±3.71	82±7.16	72±6.18	71.25±3.47
DO (Mg/L)	7.325±0.26	6.970±0.29	7.877±0.27	7.365±0.09	7.457±0.07	7.925±0.30	8.137±0.28	7.900±0.26	8.437±0.19
TDS (Mg/L)	30.25±2.95	79.75±8.08	68.25±6.34	46.75±3.90	48.00±3.24	37.25±1.80	40.75±4.21	36.00±3.11	35.50±1.85
Turbidity (NTU)	57.4±18.12	347.8±178.91	156.9±72.88	148.3±53.00	126.3±36.18	125.5±34.58	125.4±47.95	72.5±21.60	64.5±14.89
Temperature (oC)	21.73±0.90	20.52±0.41	19.72±0.48	17.51±0.36	18.42±0.30	16.51±1.12	17.55±0.81	15.19±1.00	13.72±0.70
TSS (Mg/L)	23.67±6.20	135.50±51.58	111.16±25.46	120.91±5.39	108.54±7.48	86.58±15.53	95.25±18.53	65.50±19.52	37.12±10.70
Sulphate (Mg/L)	4.74±2.32	8.31±2.74	9.85±1.03	5.13±1.27	5.83±0.60	11.90±6.92	3.17±1.58	2.80±0.98	5.53±0.78
Phosphate (Mg/L)	0.015±0.01	0.086±0.02	0.064±0.02	0.056±0.03	0.056±0.02	0.040±0.01	0.036±0.01	0.067±0.02	0.042±0.01
Nitrite (Mg/L)	1.399±0.80	0.908±0.57	0.810±0.46	0.424±0.24	0.328±0.18	0.399±0.23	0.464±0.26	0.458±0.29	0.348±0.22
Nitrate (Mg/L)	0.319±0.25	0.113±0.08	0.143±0.08	0.071±0.05	0.150±0.07	0.044±0.02	0.096±0.06	0.043±0.02	0.077±0.04
TP (Mg/L)	0.078±0.03	0.196±0.04	0.206±0.05	0.211±0.05	0.173±0.03	0.087±0.02	0.165±0.02	0.186±0.04	0.152±0.04
TN (Mg/L)	1.675±0.88	1.172±0.72	1.375±0.73	0.967±0.47	1.008±0.60	0.928±0.53	0.938±0.52	0.933±0.54	0.905±0.53

A- Alumuli at Ngueno, KG- Kibingei at Daraja Mbili, KS- Kibisi at Matisi, K1- Kuywa at Kuywa market, K2- Kuywa at Nakoyonjo, T1- Teremi at Kimorong falls, E- Emia at confluence with Teremi, T2- Teremi at confluence with Emia, KM- Kimurio at Chepyuk

Water quality parameters (physical and chemical) varied considerably among the nine sampling sites of the Kuywa River (Table 4). The altitude of the sites ranged between 1440m at site A and 2304m above sea level at site KM. The average stream depth at the sampling sites ranged between 0.15m (A) to 0.61m (KM), while the stream width ranged between 1.8m (A) and 7.02m (K2). Site K1 was found to have the highest discharge (3.09m^3/s) followed by K2 (2.69m^3/s) and the lowest being A (0.11m^3/s). Physical parameters of a stream have a direct influence on water quality. For instance the depth of a stream determines the penetration of sun rays which in turn determines stream water temperature. The discharge of a stream determines the dilution effects on pollutants as well as the stream water temperature (Masese, Muchiri & Raburu, 2009). On the other hand the wider the stream, the more it exposes water into heating thus raising the stream water temperature (Arthington, Naiman, Mcclain, & Nilsson, 2010). These physical characteristics of the Kuywa River are consistent with all other headwaters streams which have low discharge, narrow width and shallow depths. However, Kuywa River due to its geological formation, it does not form deep incisions of valleys as many head waters streams. England & Rosemond (2004) while studying on small reductions in forest cover and how it weakens terrestrial aquatic linkages in headwater streams, established that all headwater streams are characterized by low discharge and low depth. The early morphological and hydrological studies show that rivers at the headwaters are younger and advance and increase in both discharge and depth downstream towards higher order streams (Strahler, 1952) .This may have been the reason of having a stream where site A was located to be small in nature compared to other streams. As noted earlier not all sampling sites were located in the main trunk of the Kuywa River. The size of the catchment serving the stream determines the physical characteristics of the stream. The mean values and SE of water quality parameters are summarised in Table 4.

Percentage riparian vegetation cover did not follow any pattern (Table 4). Site K1 which had mature planted riparian vegetation cover had the highest value (80%) and site T1 which used to be a grazing ground but now fenced had lowest (5%). The control sites (KM) had 50% riparian vegetation cover (Table 4). The difference in canopy cover were due to the different human activities being undertaken on the riparian zone of the Kuywa River. The activities undertaken within the riparian zone of river Kuywa included agricultural cultivation, animal grazing, horticultural farming, washing and bathing, animal watering and brick making (Nyakora & Ngaira, 2014). Although sites K1 and KS were in intensive agricultural area, their high riparian vegetation cover was due to the efforts of the community to replant indigenous riparian vegetation along the river bank (KUWRUA, 2008). However, site A had been preserved by the sugarcane company to prevent soil erosion from the plantation. The lowest percentage of riparian vegetation cover experienced at site T1 was attributed by the grazing effect of the animals for a long time, however, at the time of the study the zone had been fenced off and young indigenous trees planted to rehabilitate the area. Riparian zones used for grazing take a long time to heal from disturbance. Amy and Robertson (2001) established a strong relationship between livestock management and ecological condition of riparian habitat at Murrumbidgee River Southern Australia and concluded that sites take up to 50 years to regenerate and assume pristine condition after being fenced off from the animal interference. Furthermore, it is the riparian vegetation cover is important for the health of a stream since it regulates in-stream temperature, regulate in-stream primary production, and shading of leaves provide CPOM to supply food and shelter for aquatic fauna (England & Rosemond, 2004; Newham et al., 2011).

The differential local riparian vegetation cover in the nine Kuywa River sites, may have exerted different influence on food web through autotrophic pathways via differential algal availability as proposed by Mann (1998) and Monour, Gilbert and Lecerf (2014). The results show a clear upstream-downstream trend in the pH in the main Kuywa River and its tributaries (Table 4). The pH decreased in the downstream direction except for site KM (control site) (Table 4). The highest value recorded was 8.2 (T2) while the lowest was 7.3 (A). The control site KM had pH of 7.8. These values of pH may have been controlled by the human induced factors rather than natural conditions. The human factors which affect pH of water in a stream mostly comprise the use of inorganic fertilizers in agricultural farms (Gicheru, 2004). The soils in Kuywa catchment originated from weathering volcanic rocks formed during Mt. Elgon. According to Batjes and Gicheru (2004), Kuywa catchment soils are young black volcanic originating from Mt. Elgon eruptions. The soils are acidic humic which should dominate the entire river system. Therefore, the more acidic water downstream of the Kuywa compared to the control site at the top, may be attributed by the use of fertilizers in agricultural farms. This finding is contrary to the one of Kilonzo et al. (2014) conducted in Mara River Basin and attributed the decline of pH values down-stream to the rock composition. Changes in geological condition could have likely determined the hydrochemistry of the water in Kuywa River equally in all sites. However, this finding support Hornung and Reynolds (1995) who argue that acidification of streams may result from deposition and input of fertilizers in the catchment. Apart from the geology of the catchment, human activities impact an influence of pH in the stream system.

All the nine sites were well oxygenated (>6.97mg/l) (Table 4). However, site KM which was the control site had the highest oxygen concentration (8.4mg/l) while KG had the lowest (6.9mg/l). The trend was clear that the concentration of oxygen decreased as one moves down-stream of the river (Table 4). Stream/river may be depleted of oxygen due to microbial activities in nutrient rich water. Greenway (2007) established that oxygen may be depleted from water under eutrophic condition caused by runoff from agricultural and pasture farm land where pollutants which contain phosphorus and nitrogen are common. Apart from oxygen diffusing from the surrounding air, other sources of oxygen in water include aeration through tumbles over falls and rapids and as a waste product of photosynthesis (Hughes et al., 2010). However, care should be taken when interpreting oxygen values as it is also affected by altitude and temperature (Williams, 1998). This may have been the reason for having low oxygen concentration at the lower sites of Kuywa compared to the stations at the headwaters. Phosphorus and nitrogen increases bacterial activities in water thus leading to oxygen depletion (Greenway, 2007). Excessive nutrient loading into surface water is considered to be one of the major factors of oxygen depletion (Fang, Yang, Pu, Chang, & Ding, 2004). This is because nitrogen and phosphorus are the major control factors for propagation of algae (Tong, Yang, & Pu, 2003). However, the sites are considered well oxygenated since up to 5 parts per million (ppm) of DO is the minimum amount that will support a large diverse of aquatic fauna (Mallya, 2007).

The trend depicted in temperature within Kuywa River, followed the altitude of the sites (Table 4). The lowest temperatures were recorded at site KM (13.7^{o}C) which was at the highest altitude (2304m a.s.l.) (Table 4). The highest temperature was recorded at site A (21.7^{o}C) which was at the lowest ridge (1440m a.s.l). However, site K1 was found to have a lower temperature than those higher than site K2 which is higher in altitude than it. This could be as a result of K1 having a dense canopy of riparian vegetation. This finding is consistent with that of Monoury, Gilbert, and Lecerf (2014) who established that riparian forest canopy moderates water temperature which is a key mechanism by which land influences stream ecosystem.

Turbidity levels increased down-stream of Kuywa River except at site A which was a small tributary in sugarcane plantation (Table 4). Turbidity is governed by the land use adjacent through which the stream flows. The highest turbidity was recorded in KG (347±178 NTU) while the lowest was recorded in site KM (64±14 NTU). Lower turbidity values in site KM was attributed to the less human activities taking place above this site. The rest of the sites had intensive agricultural activities coupled with the livestock rearing which increased erosion and subsequent sedimentation in river Kuywa. This is similar to the findings of Hoorman and McCutcheon (2005) who noted that the catchment especially that with vegetation along the stream riparian areas has less sediment yield to water bodies since the vegetation capture water and filter it through the soil before reaching the stream. The lower sites may have also got high values of turbidity due to accumulation of sediment in large areas. This is consistent with the findings of Nilson et al. (2015) who established that a large area of rehabilitation is required to improve the water turbidity since sediments are produced from large scale points.

Table 4 shows that nutrients in the nine sites of Kuywa River varied greatly. This study established a steady increase in reactive phosphorous (orthophosphate) downstream from site E (0.04mg/l) to KG (0.086mg/l) (Table 4). Site T2 had exceptionally high orthophosphate (0.067mg/l) compared to E which was adjacent to it. Site A which was located at a tributary within the sugarcane nuclear plantation recorded the lowest average value (0.015mg/l). The control site KM had 0.04mg/l concentration of orthophosphate, which was higher than site A and site E.

All the study sites had higher values of TN compared to the reference site (KM) (Table 4). All sites had relatively the same concentration of total nitrogen except sites A (1.675mg/l) and KS (1.375mg/l) (Table 4). However, the concentration of total phosphorus did not show a clear trend, with site A having the lowest concentration (0.078mg/l). The control site KM had also nearly the same concentration as the rest of the sites with a value of 0.152mg/l (Table 4). Nitrites showed a trend of increase in concentration downstream of the Kuywa with sites KM and K2 having the lowest (0.348mg/l and 0.328mg/l respectively) and site A having the highest (1.399mg/l) (Table 4). Similarly, site A had the highest nitrates (0.319mg/l) while site T1 and T2 had the lowest (0.044mg/l and 0.043mg/l, respectively). The control site KM had slightly higher nitrates than the lowest sites (0.077mg/l) (Table 4). These differences may be attributed to river systems including the Kuywa River that are greatly impacted by sediment deposits.

Sediment deposits may act as either nutrient and contaminant source or sink, potentially affecting the nutrient dynamics of entire water body (Greenway, 2004). In some watersheds, particularly those that are heavily fertilised, sediments may yield large quantities of phosphorus and nitrates to the downstream water bodies (Kemdirim, 2005). Thus, the increase in parameter values of nutrients more especially sites with poor riparian vegetation compared to good riparian vegetation could be explained the transportation of TN and TP in the sediments from the catchment.

Studies undertaken by Machiwa and Tungu (2005) reported that 50-80% of phosphorus and nitrogen enter large water bodies via atmospheric deposition either with rainfall (wet deposition) or winds (dry deposition). This implies that part of the nutrients dissolved in Kuywa River water may have originated from agricultural farms outside Kuywa catchment and deposited here by either rainfall or wind. Odada, Ochola, and Olago (2005) identified improper land use practices that lead to non-point pollution as some of the sources of nutrient loading. In consistent with Regional-Transboundary-Diagnostic-Analysis-(RTDA) (2005) phosphorus (39,978 tonnes/year) and nitrogen (167,650 tonnes/year) entering Lake Victoria originate from atmospheric deposition, representing 60-80% of total deposition, while rivers were found to be the second most important load source into the lake with an estimate of 9,250 tonnes/year of total phosphate and 38,800 tonnes/year of total nitrogen.

In testing whether the values of different water quality parameters at different sites where statistically significant t-test was used and values enumerated in Table 5. The control site KM was used as the reference site and the eight sites taken as the test sites.

Table 5: Results of paired t-test between water quality indicators from study sites and control site.

Parameter/Sites	**A**	**KG**	**KS**	**K1**	**K2**	**T1**	**E**	**T2**
Temp	0.00036**	0.0027**	0.0104*	0.0201*	0.0177*	0.0721	0.0641	0.4272
pH	0.1686	0.2443	0.2555	0.4533	0.412	0.4637	0.1464	0.0323*
Ec	0.2815	0.0031**	0.0176*	0.0393*	0.0144*	0.474	0.1784	0.9124
TDS	0.3154	0.0196*	0.0143*	0.043*	0.0126*	0.4222	0.1965	0.8788
DO	0.002**	0.0167*	0.029*	0.0181*	0.0152*	0.1632	0.2421	0.2904
Turb	0.7758	0.1996	0.259	0.153	0.13	0.0558	0.3163	0.7645
TSS	0.4513	0.1896	0.1143	0.0046**	0.0237*	0.0023	0.0828	0.3699
Phos	0.0111*	0.152	0.4282	0.7004	0.6532	0.8861	0.7675	0.3681
NO_2	0.1763	0.2053	0.1711	0.2535	0.8429	0.5509	0.3205	0.1966
NO_3	0.3432	0.4061	0.2071	0.813	0.2748	0.2458	0.4634	0.3364
TP	0.2084	0.4591	0.4367	0.4257	0.5148	0.1637	0.7855	0.359
TN	0.1662	0.2809	0.158	0.4015	0.2888	0.7872	0.4278	0.1995
Q	0.1642	0.9513	0.0575	0.1168	0.062	0.1012	0.0916	0.0053**

Values in table are two-tailed p-values. * means statistically significant at the 0.05 level,
**statistically significant at the 0.01.
DO=Dissolved Oxygen, TSS=Total Suspended Solids, TP=Total Phosphorus, TN=Total Nitrogen,
Temp=Temperature, Ec=Electrical conductivity, TDS=Total Dissolved Solids, Turb=Turbidity,
Phos=Phosphorous, NO2=Nitrites, NO3=Nitrates, Q=Discharge

As compared to the control site (KM), mean temperature and DO of all sites except site T1, E and T2 were statistically significant ($p<0.05$) (Table 5). Electro conductivity and TDS their difference was significant ($p<0.05$) for sites KG, KS, K1 and K2. PH was only significant ($p<0.05$) at site T2. However, TSS was significant ($p=0.0046$) at site K1 only. Moreover, turbidity, nitrites, nitrates, TP and TN had no significant difference with the reference site (KM). Mean oxygen concentration was not very significant at most of the sites when compared to the control site KM (Table 5). This could be due to the mixing of water caused by a significant drop in altitude between stations (Busulwa & Bailey, 2004). However, the significant difference in means experienced in site A dissolved oxygen may be attributed to the topography traversed by the stream which is measured at point A. Likewise, the temperature was significantly different between some sites and KM. The difference in temperature may be attributed to altitude and the riparian cover at sites A and KG which had open and patchy canopy. This is consistent with Giller and Malmsqvist (1998) who argue that vegetation cover limits solar radiation reaching the water thus contributing to the minimal fluctuation of the water temperature.

4.2.2 Benthic macroinvertebrate species abundance in Kuywa River

Benthic macroinvertebrates sampled at the nine sites of Kuywa River demonstrated a wide difference between the sites and species abundance as presented in Appendix 1.

Appendix 1 explains the abundance of species collected at the nine sites of Kuywa River between January, to October, 2016. A total of 7,444 benthic macroinvertebrate individuals belonging to 73 genus of 41 families in the nine insect orders were collected Appendix 1. The nine insect orders included Odonata, Ephemeroptera, Plecoptera, Tricoptera, Coleoptera, Hemiptera, Diptera, Lepidoptera, three orders from class annelids (Hirudinea, Herodinea, and Oligochaeta) and Decapoda were collected from the nine sites during the study period. The species abundance obtained are comparable with other studies carried out more especially in rivers with Lake Victoria Basin. For instance, Orwa et al. (2013) reported a total of 3,508 macroinvertebrate individuals belonging to 44 genera, 11 orders and 38 families collected at six sampling sites seven times in Nyando River. While studying on the macroinvertebrate structures in Kipkaren River, Aura et al. (2011) collected a total of 1,499 individuals belonging to 31 genera, 13 orders and 28 families from 7 sites done only once. The trend is the same with also Masese et al. (2009) who collected 7,333 individuals belonging to 70 genera, 13 orders and 50 families from 6 sites of Kipkaren River collected 6 times. The numbers of individuals, species, and orders obtained reflected what other studies obtained thus indicative of the structure in Lake Victoria streams. Further this finding indicates that in Lake Victoria Basin, surface macroinvertebrates are dominated by class insector.

In general, macroinvertebrate communities were dominated by two orders, Diptera (53.2%) and Ephemeroptera (32.3%) (Table 6A-G). The rest of the 10 orders represented 14.5%. Ephemeroptera was the most diverse and abundant order which possessed 14 taxa and comprised about half percentage of total abundance in the Kuywa watershed. Tricoptera showed a lower diversity and abundance than Ephemeroptera. Diptera possessed 11 taxa. Among them, Simulidae was the most abundant genus possessing 46.6% at site KM.

The Order Diptera was the most abundant during the study period, being predominant in the process of decomposition of detritus. Another role of these organisms has been reported in other studies, which represent them as essential in the detritus recycling. Thus, the results of this study supports the findings of Moretti, Goncalves, Ligeiro, and Callisto (2007), Ligeiro, Moretti, Goncalves, and Callisto (2010), Goncalves, Rezende, Franca, and Callisto (2012) and Biasi et al. (2013) which also pointed that the Chironomidae (Diptera) dominance associated with plant substrate in the decomposition process. Chironomidae are found in great geographical distribution due to their adaptation to wide range of habitats. The Chironomidae larvae are associated with inorganic and organic substrates: from silt, sand, pebbles, cobbles, boulders, and bedrock to vascular plants, leaves, and wood (Institute of freshwater ecology, 1997). They may occur on surface of substrate or burrowed. Because this group is important for nutrient recycling, it might be responsible for structuring entire community of benthic macroinvertebrate, as they are considered generalists, allowing them to colonize different types of detritus, regardless of its quality (Goncalves et al., 2012).

4.2.3 Water quality parameters and benthic macroinvertebrate species abundance

Spearman's rank correlation for water quality parameters and benthic macroinvertebrate species abundance indicated that no particular physico-chemical variable was significantly correlated to all benthic macroinvertebrate species (Table 6A-C). Furthermore, some water quality parameters were negatively correlated while others were positively correlated.

Table 6 A-C: Spearman's rank correlation between macroinvertebrate species abundance and water quality parameters.

A

Species/water quality parameter	**PO_4**		**NO_2**		**NO_3**		**TP**		**TN**	
	r	**ρ**	**r**	**ρ**	**r**	**ρ**	**r**	**ρ**	**r**	**ρ**
Megalagrion			-0.70*	0.018	0.61*	0.039				
Diplacodes							0.655*	0.039		
Baetis			-0.93**	0					-0.72*	0.015
Euthraulus			0.72*	0.015						
Hydrovatus			0.62*	0.037						
Gerries			0.71*	0.017					0.59*	0.046
Elmnae			-0.60*	0.043						
Leptophlebiidae							-0.766*	0.013		
Oligoneuridae							0.764*	0.014		
Elassoneuria									-0.72*	0.015
Leptoceridae	0.700*	0.018			-0.65*	0.029				
Ephemerella					0.70*	0.017	-0.76*	0.014	-0.60*	0.042
Limonia							-0.63*	0.047		
Naucoris			0.67*	0.0248						
Synclita									-0.71*	0.016
Macrobdella					0.83**	0.003			-0.85**	0.002
Actnonaias					0.62*	0.037			-0.63*	0.035

Taxa not shown on the table had no significant correlation. **. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

PO_4- Phosphate, **NO_2-** Nitrites, **NO_3-** Nitrates, **TP-** Total Phosphorus, **TN-** Total Nitrogen. **A-** Alumuli at Ngueno, **KG-** Kibingei at Daraja Mbili, **KS-** Kibisi at Matisi, **K1-** Kuywa at Kuywa market, **K2-** Kuywa at Nakoyonjo, **T1**- Teremi at Kimorong falls, **E-** Emia at confluence with Teremi, **T2-** Teremi at confluence with Emia, **KM-** Kimurio at Chepyuk

B

Species/water quality parameter	Alt		Q		CC		pH		DO	
	r	ρ	r	ρ	r	ρ	r	ρ	r	ρ
Baetis	0.77*	0.008					0.58*	0.05	0.68*	0.021
Euthraulus									-0.63*	0.034
Hydrovatus	-0.73*	0.014					-0.73*	0.014		
Gerries	-0.59*	0.046	-0.59*	0.046			-0.59*	0.046	-0.73*	0.013
Polypotomus	-0.63*	0.035							-0.68*	0.023
Lepidostoma			0.59*	0.048						
Hexatoma					0.83**	0.003				
Belostoria					0.73*	0.013				
Leptophlebiidae	0.68*	0.022								
Oligoneuridae			0.71*	0.017						
Elassoneuria	0.83**	0.003					0.85**	0.002	0.78**	0.007
Hydropsyche									0.64*	0.031
Ariacalis					-0.63*	0.034				
Ephemerella	0.82**	0.003					0.78**	0.006	0.75**	0.01
Simulium					0.62*	0.037				
Leach							0.73*	0.013		
Nepus							0.71*	0.017		
Naucoris			-0.59*	0.048						
Notonectidae					-0.69*	0.02				
Synclita	0.71*	0.016							0.79**	0.006
Macrobdella	0.87**	0.001					0.85**	0.002	0.90**	0
Mesovelia										
Actnonaias	0.68*	0.022					0.60*	0.046	0.91**	0

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Alt- Altitude, **Q-** Discharge, **CC-** Canopy Cover, **DO-** Dissolved Oxygen. **A-** Alumuli at Ngueno, **KG-** Kibingei at Daraja Mbili, **KS-** Kibisi at Matisi, **K1-** Kuywa at Kuywa market, **K2-** Kuywa at Nakoyonjo, **T1-** Teremi at Kimorong falls, **E-** Emia at confluence with Teremi, **T2-** Teremi at confluence with Emia, **KM-** Kimurio at Chepyuk

C

Species/water quality parameter	TDS		Tb		T		TSS		SO_4	
	r	ρ	r	ρ	r	ρ	r	ρ	r	ρ
Diplacode									0.73*	0.013
Baetis					-0.67*	0.025				
Euthraulus					0.65*	0.029				
Hydrovatus					0.62*	0.037				
Gerries					0.71*	0.017				
Goerodes									0.71*	0.017
Ecnomus									0.71*	0.017
Astacus			-0.64*	0.032					-0.78**	0.007
Haplogenis					-0.58*	0.05				
Elassoneuria					-0.66*	0.028				
Leptoceridae	0.59*	0.047								
Mesoperla									0.633*	0.034
Ephemerella									-0.60*	0.042
Leach									-0.73*	0.013
Nepus									-0.71*	0.017
Notonectidae									0.64*	0.032
Pleidae	0.78**	0.006	0.78**	0.006			0.78**	0.006		
Tubifex									-0.84**	0.002
Lumbricus									-0.67*	0.024
Macrobdella					-0.85**	0.002				

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

TDS- Total Dissolved Solids, **Tb-** Turbidity, **T-** Temperature, **TSS-** Total Suspended Solids, SO_4=Sulphate. **A-** Alumuli at Ngueno, **KG-** Kibingei at Daraja Mbili, **KS-** Kibisi at Matisi, **K1-** Kuywa at Kuywa market, **K2-** Kuywa at Nakoyonjo, **T1-** Teremi at Kimorong falls, **E-** Emia at confluence with Teremi, **T2-** Teremi at confluence with Emia, **KM-** Kimurio at Chepyuk

In the current study, three aquatic macroinvertebrate species were highly positive correlated with the altitude (Table 6B). These were *Elassoneuria sp*. (Ephemeroptera) (r=0.83, ρ=0.003) *Ephemerella sp.* (Ephemeroptera) (r=0.82, ρ=0.003) and *Macrobdella sp.* (Gnathobdellida) (r=0.87, ρ=0.001) (Table 6A-C). Other species which were positively correlated with altitude included *Actnonaias sp.* (Unionoida), *Synclita sp.* (Lepidoptera), *Leptophlebiidae sp.*

(Ephemeroptera*) and Baetis sp*. (Ephemeroptera). On the other hand *Polypotomus sp., Hydrovatus sp.* (Coleoptera) and *Gerries sp.* (Hemiptera) showed a significant negative correlation (r= -0.63, -0.73 and -0.59 respectively) (Table 6B). The species which were positively correlated were the sensitive species and more so those which require higher dissolved oxygen to survive. The higher altitude favoured high dissolved oxygen in stream water while higher temperatures limits the oxygen concentration. Higher altitude lead to lower temperatures and thus higher oxygen concentration. Further, high temperature promotes aquatic processes which reduce air concentration in streams. Chapra (1997) indicates that water temperature has a direct impact on anabolic and catabolic processes that occur in water bodies, and also influences the concentration of dissolved gases. This may also account for higher oxygen concentration observed at higher altitude sites which were cooler compared to lower altitude sites which were warmer.

The pH values of the nine sites of Kuywa River also correlated with the same trend of altitude. *Elassoneuria sp.* (Ephemeroptera), *Ephemerella sp.* (Ephemeroptera), and *Macrobdella sp.* (Gnathobdellida) highly positive correlated with pH (r= 0.85, 0.78 and 0.85 respectively) (Table 6B). *Hydrovatus sp.* (Coleoptera) and *Gerries sp.* (Hemiptera) were negatively correlated with pH (r=-0.73 and r=-0.59 respectively). This finding shows that *Hydrovatus sp.* And *Gerries sp.* are more vulnerable to alkaline stream water compared to other benthic species. On the other hand *Elassoneuria sp., Ephemerella, sp. and Macrobdella sp*. prefer more neutral water than alkaline. It could also be inferred that acidic streams are expected to have fewer individuals and taxa, compared with streams more neutral. However, the values of Kuywa River indicated that it is more neutral than acidic although it tends more to alkalinity. This is consistent with Clements (1998) who while finding out the relationship between stream pH and species abundance, EPT richness and species richness established a strong correlation between pH and species richness at different sites.

Vegetation cover has been known to modify micro-climate of a given site as well as providing litter for in-stream fauna. In this study only *Hexatoma sp.* (Diptera) was positive highly correlated (r=0.83 and ρ=0.003) with canopy cover (Table 6B). Other taxa which were significantly positive correlated included *Belostoria sp.* (r=0.73, ρ=0.013), and *Simulium sp.* (r=0.62, ρ=0.037) (Table 6B). Two species *Ariacalis sp.* (Plecoptera) and *Notonectidae sp.* (Hemiptera) were found to be significantly negative correlated with canopy cover. *Hexatoma sp*. Which was abundant and positively correlated with canopy cover is a shredder feeding group and therefore abundant in close-canopy streams where their food in form of CPOM is in abundance. *Belostoria sp.* and Notonectidae family are predators and their correlation might have been attributed to the abundance of shredders which they feed on in close-canopy sites. Similar results has been reported by Masese et al. (2013) who found shredders being diverse and abundant in closed-canopy forested streams of Moiben River.

Since Kuywa River is a perennial river, discharge was only significantly correlated to four taxa ($p<0.05$). *Lepidostoma sp.* (Tricoptera) and *Oligoneuridae sp.* (Ephemeroptera) were significantly positive correlated to discharge (r=0.59 and 0.71 respectively) while *Gerries sp.* (Hemiptera) and *Naucoris sp.* (Hemiptera) were significantly negative correlated (both r= -0.59) to discharge (Table 6B). This implies that hydrological regime is one of the most important factors influencing river systems as well as aquatic macroinvertebrate assemblages found within them. Malard, Uehlinger, Zah, & Trockner (2006) in their study on flood-pulse and river landscape dynamics established that discharge fluctuations may affect many physical parameters which determine ecosystem stability. Changes in physical parameters may result from the lowered current velocity, depth, area of flooded streambed, increased nutrient concentration and dissolved solids due to decreased discharges (Monk, Wood, Hannah, & Wilson, 2008). Further, Monk et al. (2008) argues that, decreased discharge leads to increase in water temperature, conductivity, and sedimentation. This study also indicates that individual groups of water organisms can exhibit a variety of responses to changes in discharge. Some organisms may profit while others can be fundamentally endangered; others still may be able to adapt or even withstand short term changes (Wyer et al., 2010). Site A was most affected by high discharges during the high precipitation. This finding is supported by Adámek, Konečná, Podhrázská, Všetičková, and Jurajdová (2016) who established that small stream flowing through large monoculture field complex are highly vulnerable to extreme and sudden short-term high discharge during severe precipitation events. According to Gjerlov, Hildrew, and Jones (2003), invertebrate communities generally react to floods with a reduction in density and taxonomic richness. However, the effect is short-lived due to invertebrates' high resilience to perturbation (Suren & Jowet, 2006). This may have contributed to changes in macroinvertebrate assemblages seasonally, although in the case of flash floods in short lived as discussed above.

Physical parameters including total suspended solids, total dissolved solids and turbidity were only correlated to one or two species. *Pleidae sp.* (Hemiptera) was strongly positive correlated with TSS, TDS and turbidity ($r=0.78$, $p<0.01$) (Table 6C). However, *Leptoceridae sp.* (Tricoptera) was also significant positively correlated to TDS ($r=0.59$, $p<0.05$) and *Astacus sp.* (Decapoda) significant negatively correlated to turbidity ($r= -0.64$, $p<0.05$) (Table 6C). The mix up of the species positively correlated with TDS, TSS, and turbidity may be attributed to the upper catchment characteristics of Kuywa River. Kuywa River is a headwaters stream originating from a well conserved forested area but with wild animals inside. The wild animals in in the national park disturb water during their watering thus increasing turbidity. The dense riparian vegetation drops woody debris and litter into the stream which increases suspended solids. These woody particulate matter form the food and habitat for most of the macroinvertebrates. This is also consistent with Kaufmann and Faustini (2012) who established that streams with minimal disturbed riparian forest contribute branches and large wood to channels, thereby increasing habitat complexity and habitats that favour increased abundance of macroinvertebrates.

Stream temperature may be influenced by a number of processes including the removal of riparian vegetation, urban stormwater runoff and wastewater effluent (Kinouchi, Yagi, & Miyamoto, 2006). Temperature showed a strong significant negative correlation with *Macrobdella sp.* (Gnathobdellida) (r= -0.85, p=0.002) and significant negative correlation with *Baetis sp., Haplogenis sp.* and *Elassoneuria sp*. (r= -0.6, -0.58, -0.66 respectively p<0.05) (Table 6C) which are both from Ephemeroptera order. On the other hand a significant positive correlation between water temperature and taxa was observed with *Euthraulus sp.* (Ephemeroptera) (r=0.65, p=0.029), *Hydrovatus sp.* (Coleoptera) (r=0.62, p=0.037) and *Gerries sp.* (Hemiptera) (r=0.71, p=0.017) (Table 6C). The increase in stream temperature reduces the amount of dissolved oxygen in stream water thus discouraging the abundance of intolerant species such as Haplogenis sp. This study finding is similar to Quinn, Hickey, and Vickers (1994) who established in New Zealand Rivers that many invertebrate species were sensitive to high temperatures; for example mayflies and stoneflies were impacted by water temperatures greater than 20^{o}C.

Dissolved oxygen was linked to different taxa in the present study. Dissolved oxygen was determined to be the key variable with very strong positive correlation with *Elassoneuria sp.* (Ephemeroptera), *Ephemerella sp.* (Ephemeroptera), *Synclita sp.* (Lepidoptera) and *Macrobdella sp.* (Gnathobdellida) (r= 0.78, 0.75, 0.79 and 0.90 respectively p<0.01) (Table 6B). *Hydropsyche sp.* (Tricoptera) and *Baetis sp.* (Ephemeroptera) were significant positive correlated (r=0.64 and 0.68, p<0.05) but not strong (Table 6B). Three taxa, *Euthraulus sp.* (Ephemeroptera) *Gerries sp.* (Hemiptera) and *Polypotomus sp.* (Tricoptera) were significant negatively correlated with oxygen (r= -0.63, -0.73 and -0.68 respectively, p<0.05). The amount of oxygen dissolved in stream water is important for macroinvertebrate survival. Other studies including Connolly, Crossland, and Pearson (2004) and Holland, Duivenvoorden, and Kinnear (2014) have established oxygen to be one of the main factors influencing macroinvertebrate composition in stream. However, in Kuywa River there were a number of macroinvertebrate species which seemed to be tolerant to low oxygen concentrations (such included: *Lepidostoma sp., Hexatoma sp., Belostoria sp., Mesovelia sp*., etc.). However, when only pollution-tolerant macroinvertebrates are found in a stream, it's an indicator that only these organisms can survive in that stream. But a restored stream it is hoped to find more pollution-sensitive and tolerant macroinvertebrates living together which was the case of Kuywa River. DiDonato, Summers, and Roush (2003) assert that, some tropical freshwater macroinvertebrate taxa can tolerate as low as 10% oxygen saturation levels except for Ephemeroptera, which are generally sensitive to low dissolved oxygen. Dissolved oxygen, which is affected by multiple factors, has been shown to decrease with increasing land use (Gage, Spivak, & Paradise, 2004).

The present study established that *Tubifex sp.* (Oligochaeta) and *Astacus sp.* (Decapoda) were significant highly negative correlated with sulphate (r= -0.84, p=0.002 and r= -0.78, p=0.007 respectively) (Table 6C). Other taxa which were just significantly negative correlated with sulphate included *Ephemerella sp. Leach sp., Nepus sp.,* and *Lumbricus sp.* (r= -0.6, -0.73, -0.71 and -0.67 $p<0.05$ respectively). It was also observed that some taxa exhibited a positive correlation with sulphates which included *Diplacode sp., Goerodes sp., Ecnomus sp., Mesoperla sp.* and *Notomectidae sp.* with r= 0.73, 0.71, 0.71, 0.63, and 0.64 with $p<0.05$ (Table 6C). Sulphate is essential for the growth of aquatic flora. When the concentration of sulphate is less than 0.5mg/l algal growth will not occur. However, high levels of sulphate induces eutrophication of stream water making most of the macroinvertebrates including Oligochaeta and Decapoda to reduce in abundance and taxonomic richness. High levels of sulphates especially in the form of sulphite are highly toxic to aquatic macroinvertebrates.

However, other studies show that some species of Ephemeroptera are relatively common in aquatic systems and are apparently well adapted for streams with large sediment loads, because their first pair of respiratory gills are enlarged and provide a protective covering for their other gills (Gray & Ward, 1982). This presumably shields the gills from fouling by sediments. So it is possible that this protective covering allows this species to be abundant at all conditions especially those which are inhabitable to other macroinvertebrate s.

The current study findings showed that there was no significant relationship observed between macroinvertebrate taxa and phosphorus dissolved in water. Only *Leptoceridae sp.* was highly significantly positive correlated with phosphorus (r=0.7, p=0.018) (Table 6A). Nevertheless, total phosphorus was significantly positive correlated to *Diplacode sp.* (r=0.655, p=0.039), and *Oligoneuria sp.* (r=0.764, p=0.014). Total phosphorus were significantly negative correlated to *Leptophlebiidae sp., Ephemerella sp.,* and *Limonia sp.* (r= -0.766, -0.76, and -0.63 with p<0.05 respectively) (Table 6A). Nutrients stimulate algal growth and the subsequent diurnal changes in dissolved oxygen concentration can create problems for some organisms. Respiration of algal carpet at night along with concurrent decomposition of organic matter and oxidation of ammonia can cause a dissolved oxygen deficiency. This can render the streambed unsuitable for macroinvertebrates adapted for oxygen rich streams. This study establish a higher phosphate concentration values than other Kenyan highland rivers. For instance Makoba et al. (2008) establish Njoro River to have phosphate within the range of 0.1-0.3mg/l. The higher concentration of phosphorus in Kuywa River may have been responsible for the negative correlation with the oxygen sensitive species. This finding supports the one for Wetzel (2001) who insists that phosphate is the most limiting factor for aquatic productivity and when used up, aquatic ecosystems can become poor. Apart from anthropogenic inputs of phosphate into the river system, activities of microorganisms can release adsorbed nutrients into the water column, which can increase the overall concentration of phosphate available to plants (Correll, 1998).

In the present study, only *Baetis sp.* (Ephemeroptera) (r= -0.93, p<0.01) was negative highly significant correlated with nitrites (NO_2) (Table 6A), while *Megalagrion sp*. was significant negatively correlated (r= -0.70, p<0.05). It was observed that *Euthraulus sp.*, *Hydrovatus sp.*, *Gerries sp.* and *Naucoris sp*. were significant positive correlated with nitrites (r=0.72, 0.62, 0.71 and 0.67 with p<0.05 respectively) (Table 6A). The same Table 8 shows that *Leptoceridae sp.* (Tricoptera) was the only taxon with a significant negative correlation (r= -0.65, p<0.05) with nitrates (NO_3). But four taxa were significant positive correlated with nitrates which included; *Megalagrion sp.* (r=0.62, p<0.05), *Ephemerella sp.* (r=0.7, p<0.05), *Macrobdella sp.* (r=0.83, p<0.01) and *Actnonaias sp.* (r=0.62, p<0.05) (Table 6A). Nutrient enrichment leads to increase in autotrophic biomass and production, resulting in changes to assemblage composition, including proliferation of filamentous algae, particularly where canopy cover is reduced. Similar studies have shown that nutrients accelerate litter breakdown rates and may cause decrease in dissolved oxygen and shift from sensitive species to more tolerant species (Carpenter, Caraco, Howarth, Sharpley, & Smith, 1998; Lenat & Crawford, 1994; Mainstone & Parr, 2002; Niyogi, Simon, & Townsend, 2003).

Total nitrogen (TN) has a significant positive correlation with *Gerries sp.* (r=0.59, p<0.05), while it was significantly negative to a number of taxa, which included; *Baetis sp.* (r= -0.72), *Elassoneuria sp.* (r= -0.72), *Ephemerella sp.* (r= -0.6), *Synclita sp.* (r= -0.71), *Actnonaias sp.* (r= -0.63) all with p<0.05 and *Macrobdella sp.* (r= -0.85, p<0.01) (Table 6A). Two theories have been pronounced to explain differences in macroinvertebrate reaction to disturbance. "habitat reduction" and "habitat change" theories (Lenat & Crawford, 1994), which hypothesizes that if habitat reduction were most important, one would expect all groups to be equally affected. In this case not all macroinvertebrate taxa ware affected equally since some groups seemed to be dominant over others across the sites. In addition, the overall change observed could not be termed as a replacement phenomenon.

Water quality parameters were significantly related to a number of macroinvertebrate species. *Macrobdella sp.* (Gnathobdellida) which is highly intolerant to pollution (Sawyer, 1986) was found to be negatively correlated to NO_3, NO_2 TN and TP. This is due to the fact that these nutrients lead to oxygen deficiency in pool water, which is mostly the habitat for the *Macrobdella sp.* The main effect of excess nitrogen and phosphorous in the water body is that they stimulate the growth of aquatic plants and algae blooms making the water deficient in oxygen (Kadlec & Wallace, 2009). However, other species such as *Megalagrion sp.* and *Lestes sp.* (Odonata) significantly positive correlated to the nutrients since they are more tolerant to pollution and other anthropogenic disturbances. However, we must be cautious when interpreting the nutrient loads as to how they affect taxa since their variables are multiple in nature and they may not work independently. For example altitude was one of the abiotic variables most related to variation in macroinvertebrate assemblages. These variables may show some natural variation along an altitudinal gradient (particularly canopy cover) but are also frequently related to human activities (Sheldon et al., 2012).

Water quality and the relative occurrence of habitat types also affect macroinvertebrate assemblage composition (Sheldon, 2012). For example, *Hydropsyche sp*.(Trichoptera) are found more frequently in slowly flowing waters than in pools and faster moving water where they build catchnets at downstream of woods and rocks to trap the prey. This might have been the reason for site A which had many pools to be very different by having less of the Tricoptera compared to the other sites. However, as argued by Baptista et al. (2007), and Ferreira et al. (2011), the quality of the habitat for the benthic macroinvertebrates may be affected by dissolved oxygen (DO) and level and conductivity. Moreover, these intolerant macroinvertebrates act as indicator organisms and their absence represent poor water quality (Xu & Liu, 2014).

4.2.4 Water quality parameters and benthic macroinvertebrate species richness and diversity

This section explores whether water quality parameters have an influence on benthic macroinvertebrate species richness and abundance. This has been achieved by determining the spearman rank correlation between the water quality parameters and benthic macroinvertebrate species richness and abundance. The result of the relationship between these water quality parameters and benthic macroinvertebrate species richness and abundance in Kuywa River as sampled between January and October, 2016 are given in Table 7.

Table 7: Spearman's rank correlation between water quality parameters and Simpson diversity index, Shannon-Winner diversity index and Margalef richness index for the nine sites of Kuywa River between January to October, 2016

Water quality parameters/Index	**Simpson diversity Index**		**Shannon diversity index**		**Margalef richness index**	
	r	**ρ**	**r**	**ρ**	**r**	**ρ**
Alt	0.22	0.57	0.26	0.50	-0.03	0.94
Dep	0.18	0.64	0.26	0.49	0.60	0.09
Q	0.05	0.89	-0.06	0.88	0.14	0.71
pH	0.30	0.43	0.36	0.34	0.13	0.73
DO	0.41	0.27	0.34	0.36	-0.17	0.66
TDS	0.29	0.44	0.31	0.41	**0.69***	**0.04**
Tb	0.20	0.60	0.19	0.62	0.62	0.07
T	-0.03	0.93	-0.01	0.98	0.13	0.74
TSS	0.12	0.76	0.15	0.69	0.58	0.10
SO_3	0.08	0.83	-0.06	0.88	0.12	0.76
PO_4	0.18	0.65	0.29	0.45	**0.78***	**0.01**
NO_2	0.18	0.65	0.23	0.54	0.19	0.62
NO_3	-0.08	0.84	-0.08	0.84	-0.52	0.15
TP	0.000	1.00	-0.14	0.73	0.08	0.84
TN	-0.08	0.83	-0.08	0.84	0.12	0.76

PO_4=Phosphate, NO_2=Nitrites, NO_3=Nitrates, TP=Total Phosphorus, TN=Total Nitrogen, Alt=Altitude, Q=Discharge, DO=Dissolved Oxygen, TDS=Total Dissolved Solids, Tb=Turbidity, T=Temperature, TSS=Total Suspended Solids, SO_4=Sulphate

*. Correlation is statistically significant at the 0.05 level (2-tailed).

The results of the analysis in Table 7 shows that only TDS (r=0.69, ρ=0.04) and PO_4 (r=0.78, ρ=0.01) were statistically significantly correlated with Margalef richness. Other water quality parameters which had a higher correlation value with Margalef richness although not significant were; Turbidity (r=0.62, ρ=0.07), stream depth (r=0.60, ρ=0.09) and NO_3 (r=-0.53, ρ=0.15) (Table 7). Richness may have been positively correlated to TDS due to the differential riparian vegetation cover, which influences the amount of TDS reaching the river. Raburu (2003) established an increase in benthic macroinvertebrate species richness in Nyando River which the increase in TDS and attributed it to riparian vegetation condition. This finding is also consistent to Sheldon et al (2012) who found out that in Noosa River, South East Queensland, the species richness and diversity were being governed by water quality parameters. Positive correlation for PO_4 and benthic macroinvertebrate Margalef richness index contradicts the findings of Odume (2012) who established a negative correlation. However, Odume (2012) study was based on extreme discharge of PO_4 from industrial effluent. In Kuywa River, PO_4 may be limiting factor for in-stream growth of macrophytes, and thus increase in PO_4 led to increased food production for grazers thus enhancing species richness (Masese, 2012). However, high PO_4 may stimulate algae and subsequent diurnal changes in dissolved oxygen concentration which can create problems to some benthic macroinvertebrate species (Makoba, 2008).

All water quality parameters were not significantly correlated to Shannon index and Simpson diversity (Table 7). Dissolved oxygen (DO) showed a weak correlation ($r=0.41$, $\rho=0.27$) with Simpson diversity (Table 7). Shannon diversity index normally increases as diversity increases (higher value is better). On the other hand Simpson index is a similarity index which means the higher the value the lower the diversity (lower is better). Shannon diversity index depends more on species richness and less on species abundance which means the index is sensitive to small diversity changes. Simpson diversity index takes into account more on dominant species and not affected by less abundant elements and therefore easy to show the trend in which the ecosystem is heading to. The findings of this study are consistent to that of Hodkinson and Jackson (2005) who established that benthic macroinvertebrates may be an indicator for any change in the environment through their responses at species richness and diversity. Raburu (2003) while studying on Nyando River, established a higher correlation between macroinvertebrate diversity and point source pollution. Thus diversity may increase with turbidity to some degree before it becomes an inhibiting factor (Masese, 2008).

The results in Table 7 suggested an influence of pollution on macroinvertebrate richness in Kuywa River despite introduction of riparian vegetation cover at some parts of the river stretch.

It was expected that physico-chemical would show high correlation with evenness (Malacarne, Baumgartner, Moretto, & Gubiani, 2016) but none had. However, DO which has a great influence on diversity indicated some correlation. Belsel et al. (2000) established that streams having more dissolved oxygen should have a greater diversity of species than streams with less. This result is consistent with the findings of Nilson et al. (2015) and Monour, Gilbert, & Lecerf, (2014) who established that increased oxygen concentration in the stream as a result or riparian vegetation shade increases the species diversity of that stream.

In summary, nine sites of Kuywa River experienced variations in water quality parameters and benthic macroinvertebrate species abundance and diversity. The altitude ranged between 1440m and 2304m a.s.l., stream depth between 0.15m and 0.6m, width 1.8m and 7.02m, while discharge ranged between 0.11m^3/s and 3.09m^3/s. The nine sampled sites were well oxygenated (>6.97mg/l) while temperature followed the altitude with the lowest being at KM (13.7^oC) and highest at site A (21.7^oC). Turbidity levels increased downstream and ranged between 347 NTU at site KG and 64 NTU at KM. Orthophosphate increased steadily downstream site E having 0.04mg/l and site KG 0.08mg/l. During the sampling period, a total of 7,444 benthic macroinvertebrate individuals were collected belonging to 73 genus, 41 families and 9 orders. Orders Diptera and Ephemeroptera dominated the species (53.2% and 32.3%). Spearman rank correlation for water quality parameters and benthic macroinvertebrate species abundance indicated that no particular physico-chemical variable was statistically significant correlated to all benthic macroinvertebrate species. *Elassoneuria sp.* (r=83, $\rho<0.01$), *Ephemerella sp.* (r=0.82, $\rho<0.01$) and *Macrobdella sp.* (r=0.87, $\rho<0.001$) were significant positively correlated to altitude. *Polypotomus sp., Hydrovatus sp.,* and *Gerries sp.* were significant negatively correlated to altitude (r=-0.63, -0.73, and -0.59 respectively $\rho<0.05$). The study established that *Hexatoma sp.*, *Belostoria sp.* and *Simulium sp.* were significant positively correlated to canopy cover (r=0.83, r=0.73 and r=0.62 respectively $\rho<0.05$). *Lepidostoma sp.* and Oligoneuridae were significant positive correlated with discharge (r=0.59 and r=0.71 respectively $\rho<0.05$) while *Naucoris sp.* and *Gerries sp.* were negatively correlated with discharge (r= -0.59, $\rho<0.05$). *Macrobdella sp., Baetis sp., Haplogenis sp.* and *Elassoneuria sp.* were significant negatively correlated to temperature (r= -0.85, -0.6, -0.58 and -0.66 respectively $\rho<0.05$). *Elassoneuria sp., Ephemerella sp., Synclita sp., Macrobdella sp., Hydropsyche sp.* and *Baetis sp.* were significant positively correlated to oxygen concentration ($\rho<0.05$). However, *Euthraulus sp., Gerries sp.* and *Polypotomus sp.* were significant negatively correlated to dissolved oxygen ($\rho<0.05$). Diplacode and *Oligoneuria sp.* were significant positively correlated to total phosphorus while Leptophlebiidae, *Ephemerella sp.* and *Limonia sp.* were significant negatively correlated to total phosphorus ($\rho<0.05$). *Baetis sp., Elassoneuria sp., Ephemerella sp., Synclita sp., Macrobdella sp.* and *Actnonaias sp.* were significant negatively correlated to total nitrogen ($\rho<0.05$). Further, it was established that *Megalagrion sp., Baetis sp.* and *Elmnae sp.* were significant negatively correlated to nitrites and nitrates while *Euthraulus sp., Hydrovatus sp., Gerries sp.* and *Naucoris sp.* were significant positively correlated to nitrites ($\rho=0.05$). A number of benthic macroinvertebrates species were significant negatively correlated to sulphate and they included *Astacus sp., Ephemerella sp., Leach sp., Nepus sp., Tubifex sp.* and *Macrobdella sp.* ($\rho<0.05$). These findings led to the rejection of the null hypothesis that water quality variables (e.g. turbidity, pH, total nitrogen) had no relationship with benthic macroinvertebrate species abundance in the Kuywa River. Spearman rank correlation between water quality parameters and benthic macroinvertebrate species diversity and richness indices indicated that only TDS (r=0.6, $\rho=0.04$) and PO4 (r=0.78, $\rho=0.01$) were statistically significant with Margalef richness index. Other indices were not significant. Thus the null hypothesis that water quality parameters (e.g. turbidity, pH, total nitrogen) had no relationship with benthic macroinvertebrate species diversity in the Kuywa River was rejected.

4.3 Influence of planted riparian vegetation cover on benthic macroinvertebrate species abundance in the Kuywa

Using the four criteria developed for the quantification of percentage riparian zone vegetation cover (Table 2), along with photographs taken in the field (Plates 1-9), riparian vegetation cover classification was obtained (Table 8). The scores ranged between 1 and 4, whereby 1 indicated a "poor" riparian vegetation condition, and 4 an "excellent" riparian vegetation zone condition.

Table 8: Percent riparian vegetation cover, riparian vegetation cover score, category of vegetation and site classification for the nine sampled sites in Kuywa River between January and October, 2016. Adapted from Tornblom et al. (2011) and Aura et al. (2010)

Sampling Sites	A	KG	KS	K1	K2	T1	T2	E	KM
percent riparian vegetation cover	50	20	60	80	40	5	40	25	50
riparian vegetation cover score	3	1	3	3	4	1	3	3	4
Category of vegetation	Sugar cane plantation (PS)	Planted eucalyptus (PE)	Natural conserved (PY)	Planted mature (PM)	Planted mature (PM)	Fenced and retired from grazing (F)	Planted young (PY)	Planted mature (PM)	Natural conserved (NC)
Site classification	Good	Poor	Good	Good	Excellent	Poor	Good	Good	Excellent

A- Alumuli at Ngueno, **KG-** Kibingei at Daraja Mbili, **KS-** Kibisi at Matisi, **K1-** Kuywa at Kuywa market, **K2-** Kuywa at Nakoyonjo, **T1**- Teremi at Kimorong falls, **E-** Emia at confluence with Teremi, **T2-** Teremi at confluence with Emia, **KM-** Kimurio at Chepyuk

Results in Table 8 shows that two sites, Site KM and Site K2 had "Excellent" site classification. These sites had more than 30m of riparian covered with vegetation (Table 8). Site KM was naturally conserved while Site K2 was rehabilitated by the community and fenced off to avoid the interference by the animals. Sites with intermediate score of and thus classified as "Good" included A, KS, K1, T2 and E (Table 8). These sites had patchy vegetation with some spots within 100m ridge not well covered with vegetation or not reaching 30m as given by the Water

Act, 2002. The sites which scored lowest were Site KG and Site T1. Site KG was covered by exotic trees (eucalyptus trees) however, some sections at the upstream of the river stretch was covered by indigenous vegetation. Site T1 was recently been fenced off, but still not recovered from the influence of animal grazing.

Results of Table 8 suggested an influence of riparian vegetation cover on benthic macroinvertebrate assemblages in the Kuywa River. Further the results suggested a differential health status of the Kuywa River as per the riparian vegetation cover. Headwater near pristine, site KM, showed 'Excellent' classification at the site scale (Table 8). This was as expected because this site was just outside the conserved national park. Site K2 which was also 'Excellent' had planted riparian vegetation which was mature and fenced well avoiding the grazing of animals. Site KS, T2, K1, and E had vegetation but not continuous either due to human interference of still too young to exert the influence. This may be as a result of trees and shrubs taking too long to cover the ground (Sheldon et al., 2002; Sponseller et al., 2001) to mimic the natural habitat. Even the rehabilitated riparian normally have the foot-prints of human interference indicated by habitat modification (Sanchez-Arguello, Cornejo, Pearson, & Boyero, 2010). The 'Poor' sites were site T1and KG due to having the exotic species of vegetation not preferred by the benthic macroinvertebrates. Further, exotic species of vegetation have been found not allowing indigenous undergrowth whose allochthonous organic matter afford habitat and food for aquatic macroinvertebrates (Monoury et al., 2014).

To determine whether riparian vegetation cover had influence on benthic macroinvertebrate species abundance, a spearman rank correlation procedure was performed. The spearman rank correlation between riparian vegetation cover scores and benthic macroinvertebrate abundance gave results in Table 9.

Table 9: Spearman rank correlation between percentage riparian buffer vegetation cover and benthic macroinvertebrate species abundance collected at nine sites of Kuywa River between January, 2016 and October, 2016.

Species	Order	Riparian buffer vegetation Cover r	P-value
Hexatoma sp.	Diptera	0.83**	0.003
Belostoria sp.	Hemiptera	0.73*	0.013
Ariacalis sp.	Plecoptera	-0.63*	0.034
Simulium sp.	Diptera	0.62*	0.037
Notonectidae	Hemiptera	-0.69*	0.02

* means correlation was significant at the 0.05 level (2-tailed), ** means correlation was significant at the 0.01 level (2-tailed. Other species were not significantly correlated.

Table 9 shows that only five species had statistically significant correlation with percentage riparian vegetation in Kuywa River. At 95% confidence level, *Hexatoma sp.* (Diptera) was very positively correlated (r=0.83, ρ=0.003) with percentage riparian vegetation cover, while *Belostoria sp.* (Hemiptera) and *Simulium sp.* (Diptera) were just positively correlated (r=0.73, ρ=0.013 and r=0.62, ρ=0.02 respectfully) (Table 9). It was also established that *Ariacalis sp*. (Plecoptera) and Notonectidae (Hemiptera) were negatively correlated with percentage riparian vegetation cover (r=-0.63, ρ=0.034 and r=-0.69, ρ=0.02) respectfully. Allan (2004) noted that riparian clearing/canopy opening reduces shading, causing increases stream temperature, light penetration, and plant growth. Increased temperature reduces the solubility of Oxygen in water while light penetration increases microbial activities in water. At the same time, temperature, light and sufficient nutrients promotes the growth of algae with reduces oxygen concentration in the river (Al-Qasmi & Raut, 2012). Riparian vegetation increases input of litter and wood, and retain nutrients and contaminants outside the stream water (Findlay, Quinn, Hickey, Burrell, & Downes, 2001; Gregory et al., 1991). Litter and wood provide microhabitat for some macroinvertebrates (e.g. *Hexatoma sp., Belostoria sp.,* and *Simulium sp*.) while nutrients prohibit some microinvertebrates (e.g. *Ariacalis sp.* and Notonectidae) by causing eutrophication of stream water. They further argue that riparian vegetation increase sediment trapping and decrease bank and channel erosion; alters quantity and character of dissolved organic carbon reaching streams. Furthermore, clearing of riparian lowers retention of benthic organic matter owing to loss of direct input (Gurnell, Gregory, & Petts, 1995; Stauffer, Goldstein, & Newman, 2000).

Table 9 shows that not all species of aquatic benthic macroinvertebrate respond the same with the percentage riparian vegetation cover. *Hexatoma sp*. (Diptera) which was highly positive correlated (R=0.83, $p<0.01$), and *Simulium sp.* (Diptera) and *Belostoria sp.* (Hemiptera) positive correlated (r=0.62 and r=0.73 respectfully) (Table 9) are very sensitive to dissolved oxygen and like clear water. Further, *Belostoria sp.* and *Hexatoma sp.* are very intolerant to any form of pollution (e.g. increase in nutrients). The sites with 'Excellent' riparian vegetation cover, had higher canopy cover which lowered the water temperature and thus increasing oxygen concentration. Lower temperature and high oxygen are important conditions that support diverse aquatic organisms (Narangarvuu et al., 2014). Similarly, sites which had low riparian vegetation cover and thus low canopy cover might have had high microbial growths which deprived water of oxygen making these macroinvertebrates impossible to survive. This finding is similar to Bourque and Pomeroy (2001), Findlay et al. (2001), and Stauffer et al. (2000) who established that riparian clearing/canopy opening reduces shading, causing increases in stream temperatures, light penetration, and plant growth. Conversely, *Ariacalis sp.* (Plecoptera) and Notonectidae (Hemiptera) were negative significantly correlated as they have a wide ecological tolerant to stressors. Most of the species were not significantly correlated which might be attributed by the frequent habitat disturbance which eliminate intolerant species from the river (Dudgeon et al., 2006).

A total of 7,442 macroinvertebrate individuals belonging to 73 taxa of 41 families in the 9 insect orders Odonata, Ephemeroptera, Plecoptera, Tricoptera, Coleoptera, Hemiptera, Diptera, Lepidoptera, three orders from class annelids (Hirudinea, Herodinea, and Oligochaeta) and

Decapoda were collected from the nine sites during the study period (Appendix 1). The abundance was comparable with other Kenyan Rivers. The study done by Masese et al. (2009) in Moiben River which is also a tributary of Nzoia like Kuywa established a total of 7,333 individuals belonging to 70 taxa with 108 samples and Oruta (2016) established a total of 2,970 individuals from 57 samples on Sosiani River which is also a tributary of Nzoia River. Further, the dominance of order Diptera in Kuywa River, could probably be attributed to the presence of leaf litter and other course particulate organic matter (CPOM) in some sites such as KM and K1 and thus favoured the flourishing of Chironomidae family. Moreover, Ephemeroptera majority were from Baetis genus who are scrappers, and the presence of algae especially at the sites with less canopy cover, favoured the flourishing of algae and thus supporting Baetis species of benthic macroinvertebrates. However, the less number of families such as Tipulidae sp., Potamonautidae and Lepidostomatidae may have been due to reduced riparian vegetation cover especially at sites T1, KS and KG, since they are shredders. These families had favourable temperatures as they are adapted to cold water and the tropical highlands are close to their thermal maxima (Baxter et al., 2005).

The study further sort to investigate whether different percentage riparian vegetation cover at different sites had influenced species richness, evenness and diversity. Table 10 summarizes the results of the analysis.

Table 10: Summary for benthic macroinvertebrate -species abundance, species richness, species evenness and species diversity at nine Kuywa River sites between January to October, 2016.

Site	S	N	d	J'(E_H)	H'(loge)	1-λ'
A	26	707	3.81	0.47	1.52	0.64
KG	34	312	5.75	0.68	2.41	0.80
KS	32	495	5.00	0.73	2.51	0.88
K1	31	1858	3.99	0.26	0.89	0.32
K2	35	1026	4.90	0.55	1.96	0.75
T1	29	607	4.37	0.69	2.34	0.82
E	34	843	4.90	0.72	2.55	0.88
T2	35	543	5.40	0.71	2.51	0.86
KM	28	1052	3.88	0.58	1.93	0.73

S=Richness index; N=Abundance index; d=Margalef richness; J'=Plelou's evenness; H'=Shannon index; E_H=Shannon evenness; 1-λ=Simpson diversity.

A- Alumuli at Ngueno, **KG-** Kibingei at Daraja Mbili, **KS-** Kibisi at Matisi, **K1-** Kuywa at Kuywa market, **K2-** Kuywa at Nakoyonjo, **T1-** Teremi at Kimorong falls, **E-** Emia at confluence with Teremi, **T2-** Teremi at confluence with Emia, **KM-** Kimurio at Chepyuk

The highest species richness was recorded at K2 (35) and T2 (35) while the lowest was recorded at A (Table 10). Low value Shannon diversity index was recorded at K1 (0.89). In both Shannon and Simpson diversity indices, site E (2.55) recorded highest values followed by T2 (2.51) and KS (2.51) (Table 10). It was surprising that the reference site KM was the third lowest in both Shannon and Simpson diversity indices. As per the trend in diversity also in evenness and richness, A and T1 scored the lowest followed by the reference site KM. However, KG (5.75) was found to have the highest richness score followed by T2 (5.40). On the side of evenness, KS (0.73) scored the highest value followed by E (0.72) (Table 10).

The high values of species richness in sites T2 and KG might be due to the activities being undertaken on the upstream catchment and the characteristics of riparian vegetation cover. The low taxonomic value for the reference site KM may have come from the disturbance of wild animals about 150 meters upstream of the sampling site. These two sites has less human captivities on their catchments. Furthermore, these two sites had continuous riparian vegetation for many kilometres and thus good connectivity for the organisms even when there is a disturbance. Studies carried out on the upper catchment of Nyando River (Orwa et al., 2013) established that, riparian vegetation cover has great impact on temperature and nutrient levels in a stream which consequently determines the integrity of the river system.

In contrary, site A whose catchment was the sugar cane plantation had minimum taxonomic richness due to the nutrients emanating from the use of fertilizers on farms, which lead to competition of in-stream oxygen (Oruta, 2016) and the type of riparian vegetation experienced at the site. The type of riparian vegetation determines the amounts of organic carbon produced within the stream system. The fate of terrestrial sources of organic matter in the aquatic food web, are sensitive to changes in riparian condition (e.g. increased nutrient runoff). In the absence of riparian shade, large vascular plants and filamentous algae often proliferate, restricting flow, trapping sediment and ultimately resulting in marked changes to available habitat and lowered water quality (Wade, 1994). This finding is consistence with Bunn, Davies, and Kellaway (1997) who established that excessive growth of para grass in stream channels in the sugarcane lands of northern Queensland, has had a dramatic effect on channel morphology, flood capacity and aquatic ecosystem function. Although macrophytes can be conspicuous components of larger river systems and are often assumed to be important sources of carbon for aquatic consumers (e.g. Mann (1988), Webster and Benfield (1986)), recent studies provide little evidence of a significant contribution to aquatic food webs (France, 1996; Hamilton, Lewis, & Sippel, 1992) in small streams like that at site A.

To test the null hypothesis that there are no abundance differences between the sites with excellent, Good and Poor riparian vegetation cover, ANOSIM (analysis of similarity) was used and gave the result, Global $R=0.94$ and $p=0.037$ ($p<0.1$). Thus this study rejected the null hypothesis for there was significant difference between the sites in terms of macroinvertebrate assemblages. The difference between the sites in terms of macroinvertebrates may have been attributed by the direct changes to the carbon dynamics of streams and rivers associated with riparian vegetation cover. Absence of riparian vegetation has a tremendous impact on ecosystem function and river health, particularly if coupled with increased nutrient inputs. Although eutrophication is a consequence of high nutrient levels, it is the accumulation of unconsumed plant biomass that ultimately leads to water quality problems, loss of habitat and major decline in stream ecosystem health and biodiversity (Bunn, Loneragan, & Kempster, 1995). In many cases, changes to the carbon dynamics are also accompanied by other impacts triggered by the loss of riparian vegetation. Increased water temperatures, loss of instream habitat and sedimentation make an important contribution to the demise of the stream. Bunn et al. (1995) further argues that, slight increases in light and nutrients (e.g. associated with reduced riparian cover) may have a positive influence on stream productivity, but at what threshold the system switch to excessive production of non-acceptable forms of plant production is not well understood.

The test of hypothesis indicated that there was significant benthic macroinvertebrate abundance differences between the sites which had 'Excellent', 'Good' and 'poor' riparian vegetation cover ($p<0.1$). Simulium sp. which feed on fine particulate organic matter (FPOM) from the water column using variety of filters, *Gompus sp*. which are predate on other consumers and *Baetis sp.* which are scrappers and consume algae and associated materials differentiated the sites between the 'poor' and 'Excellent'. This differentiation of sites as per benthic macroinvertebrate abundance may have been associated with the linkage that exist in riparian dominated headwater streams between course particulate organic matter (CPOM) and shredders and FPOM and collectors, and primary production and scrappers. This was evidenced by *Leptophlebiidae sp.* and *Lepidostoma sp*. which are shredders being among the highest contributors (3.21% and 3.19% respectfully) to the dissimilarity of sites. These two species are very sensitive to water quality and can survive in good water quality only (Bunn et al., 1999). On the other hand the groups 'poor' and 'Good' were dissimilar (40.61) being differentiated by scrapper feeders (*Baetis sp.*, *Elassoneuria sp.*, and *Afronurus sp*.), Filter (*Simulium sp*.) and gatherer feeders (*Chironomous sp*. and *Tricorythus sp*.). These species may have differentiated the sites as those sites with 'Good' riparian vegetation cover prevented sediments and other catchment materials from reaching the river, while those receiving sediments had plenty of gatherers. Other studies have shown that even modest riparian deforestation in highly forested catchments can result in degradation of stream habitat owing to sediment inputs (Sutherland, Meyer, & Gardiner, 2002). A comparison of two small catchments that were less than 3% non-forested with two that were 13% and 22% non-forested found the latter to have higher concentrations of suspended sediments, higher turbidity at base flow, five to nine times greater bedload transport, and greater embeddedness (Sutherland et al. 2002). However, when this interpretation has been done, care should be taken as materials in the river may be transported from a distance and get deposited in a given site especially when encountered with the obstructions (Findlay et al., 2001). Furthermore, as discussed above, the sites with closed canopy which were in sites KM and K2 prevented sun light penetration and might have limited the growth of algae (Greenway, 2004; Sheldon et al., 2012) necessary for the survival of scrappers. Nevertheless, the feeding of shredders on riparian litter affects detrital processing in aquatic systems.

The role of individual species in contributing to the dissimilarity of these nine sites with different riparian vegetation cover was implemented in the SIMPER (Similarity Percentages) procedure. Higher values for average dissimilarity (Av.Diss) indicates that the species contributed more in making the sites with different riparian vegetation cover to be less similar. Percentage contribution provides the extent to which that specific species contributes in to the total dissimilarity between the categories of sites. The scores separating sites classified as 'Poor' and 'Excellent' and those classified as 'Poor' and 'Good' are summarized in Table 11 and Table 12.

Table 11: SIMPER scores (Average abundance, average dissimilarity, contribution to dissimilarity and cumulative dissimilarity) for group Poor and Excellent riparian vegetation cover. Average dissimilarity was 34.92

	Group Poor	**Group Excellent**			
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Contrib%**	**Cum.%**
Simulium	2.9	6.51	4.49	12.85	12.85
Gompus	2.54	1.35	1.5	4.29	17.14
Baetis	6.3	5.14	1.45	4.15	21.29
Macrobdella	0.41	1.08	1.35	3.88	25.16
Afronurus	1.77	1.05	1.25	3.58	28.74
Leptophebiidae	0.9	0.98	1.12	3.21	31.95
Lepidostoma	1.52	0.8	1.11	3.19	35.14
Elmnae	0	0.76	0.94	2.71	37.84
Haplogenis	1.84	1.13	0.88	2.51	40.36
Caenis	1.27	0.6	0.84	2.41	42.77
Tricorythus	2.18	1.54	0.8	2.3	45.06
Oligoneuridae	0.61	0	0.78	2.22	47.29
Megalagrion	0.54	1.16	0.76	2.19	49.48

Av=Average, Diss=Dissimilarity, Contrib=Contribution, Cum=Cumulative

Table 12: SIMPER scores (Average abundance, average dissimilarity, contribution to dissimilarity and cumulative dissimilarity)for group Good and Poor riparian vegetation cover. Average dissimilarity was 40.61

	Group Good	**Group Poor**				
Species	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Simulium	4.95	2.9	3.66	1.05	9.01	9.01
Baetis	4.19	6.3	2.76	1.68	6.79	15.8
Elassoneuria	1.45	0.74	1.7	1.15	4.18	19.98
Afronurus	1.25	1.77	1.42	1.4	3.49	23.47
Gomphus	1.92	2.54	1.39	1.16	3.41	26.88
Chironomous	2.9	2.36	1.32	1.16	3.24	30.13
Tricorythus	1.21	2.18	1.31	1.19	3.22	33.34
Meso	0	0.96	1.21	2.16	2.98	36.32
Leptophlebiidae	0.54	0.9	1.11	1.17	2.73	39.05
Lestes	1.76	2.01	1.07	1.6	2.64	41.7
Ephemerella	0.92	0	1.07	0.53	2.63	44.32
Lepidostoma	0.94	1.52	1.01	1.2	2.48	46.81
Haplogenis	1.27	1.84	0.99	1.41	2.45	49.25

Av=Average, Diss=Dissimilarity, Contrib=Contribution, Cum=Cumulative

In Table 11 and 12, the average of the Bray-Curtis dissimilarity between the pairs of 'Excellent' and 'Poor' sites was 34.92 while that between 'Good' and 'Poor' riparian vegetation cover the average dissimilarity was 40.61%. This implied that the sites 'Excellent' and 'Poor' were 65.08% similar in terms of benthic macroinvertebrate species abundance. This was found to be made up of 12.85% from *Simulium sp.* (Diptera), 4.29% from *Gomphus sp*. (Odonata), 4.15% from *Baetis sp.* (Ephemeroptera) and the rest had insignificant contributions. The *Simulium sp*. contributed 12.85% of the total of 34.92, *Gompus sp.* gave 4.29% of this total and *Baetis sp*. gave 4.15% of the total. *Simulium sp*. declines sharply in abundance in poor vegetation cover (6.51 to 2.9), whereas, *Gompus sp.* increases in poor vegetation cover (1.35 to 2.54). This result shows that, the sites classified as "Excellent" were less than half similar with those classified as "poor" , which may be attributed by the animal disturbances at these sites. Although the riparian vegetation cover may be excellent, other disturbances may affect the structure of macroinvertebrates in a stream. Further, in Table 12 the average Bray-Curtis dissimilarity between 'Good' and 'Poor' sites in the group was 40.61, made up of from *Simulium sp.* (3.66 i.e. 9%), *Baetis sp.* (2.76 i.e. 6.79%), *Elassoneuria sp*. (Ephemeroptera) (0.74 i.e. 4.18%) and the rest being less than 3.4% contribution. This implied that the sites classified as 'Good' and 'Poor' were more dissimilar in terms of benthic macroinvertebrate abundances compared to those classified as 'Excellent' and 'Poor'. The sites classified as 'Excellent' were those planted with riparian vegetation after being identified as heavily degraded, except the control site KM. After rehabilitation it takes some time for recolonization to take place (Sheldon, 2012).

To investigate how specific genus were responsible for creating the observed gradient between sites of different riparian vegetation cover, species bubble plots was applied on multidimensional scaling (MDS). Figure 6 shows the behaviour of *Megalagrion sp.*, *Simulium sp.*, *Chironomous sp.* and *Haplogenis sp.* over the sites with different riparian vegetation cover. Circles are superimposed at each point, of size related to abundance at that site.

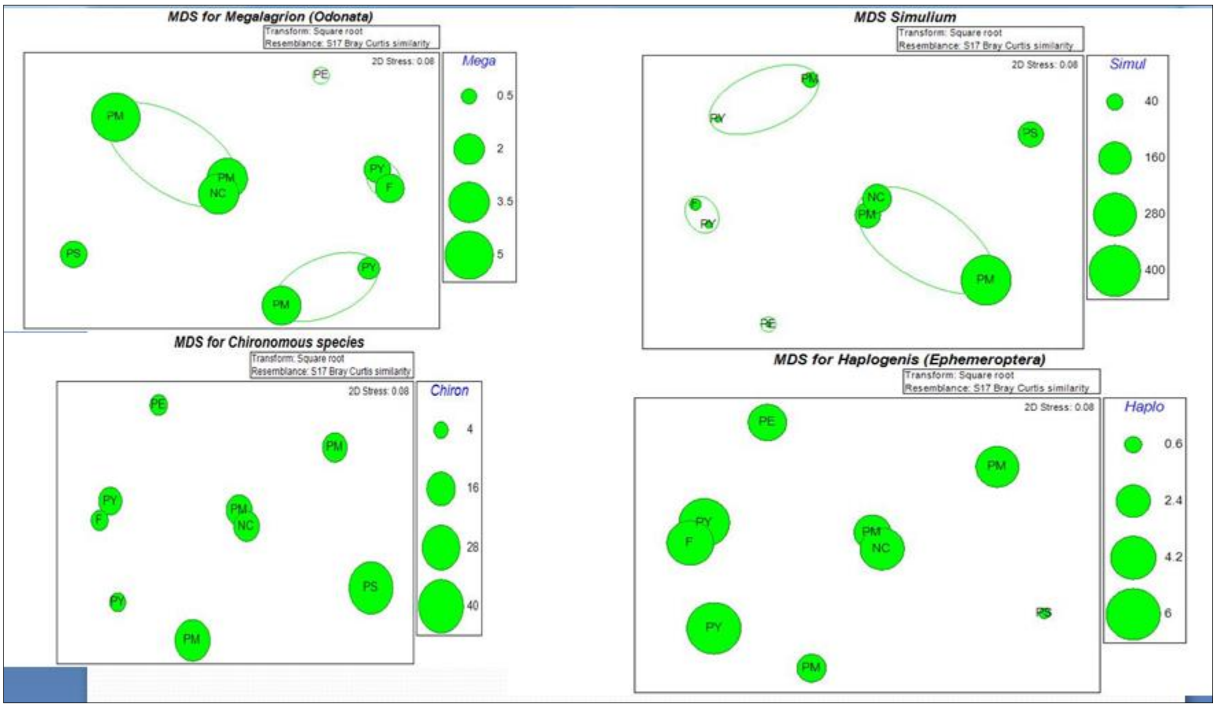


Figure 6: Kuywa River benthic macroinvertebrate abundance. MDS for *Megalagrion sp.*, *Simulium sp.*, *Chironomous sp*. and *Haplogenis sp*. with superimposed bubbles (circles) representing respective species abundance at different sites of different riparian vegetation cover. PM=planted mature vegetation, PY=planted young vegetation, PE=planted eucalyptus, NC=Natural conserved vegetation, PS=planted sugarcane, F=fenced off from animals.

MDS for *Megalagrion sp.* (Odonata) species indicated that sites with mature planted vegetation cover and those with natural conserved clustered together had a greater abundance of individuals than the sites which had young planted vegetation, planted sugarcane, planted eucalyptus trees and that which was fenced off (Figure 6). The same abundance trend was found in *Simulium sp.* (Diptera). On the other hand MDS for Chironomous sp. (Diptera) included the riparian with planted sugarcane in the same cluster with mature and natural conserved riparian vegetation cover. MDS for *Haplogenis sp.* (Ephemeroptera) was opposite of *Chironomous sp.* in that planted sugarcane riparian vegetation cover had the least macroinvertebrates compared to other sites. Most of the genus were found not to be very sensitive to this metric. *Simulium sp*. and *Chironomous sp.* which were most abundant in sites with planted mature and natural conserved riparian vegetation were from Diptera Order. The Diptera Order dominate sites with detritus materials and are involved in their decomposition (Biasi, Tonin, Restello, and Hepp, 2013). *Megalagrion sp.* was also abundant in sites with mature planted and naturally conserved riparian vegetation cover due to the availability of vegetation as they are herbivores. Odonata order where *Megalagrion sp.* belongs are sensitive to different stressors, such as pollutants (Ferreras-Romero, Marquez-Rodriguez, & Ruiz-Garcia, 2009) and temperature changes (Hassall & Thompson, 2008). This finding is consistent with Oertli (2008) who argues that species under Odonata Order have their larvae stage under aquatic environment and adult in terrestrial, hence indicative species for both aquatic and terrestrial habitats. It also supports Knight, Mccoy, Chase, Mccoy, and Holt (2005) that species under Odonata Order are indicative of riparian vegetation cover condition as they have an important role as predators, which give them a wide range of interactions with different organisms in both aquatic and terrestrial ecosystems.

On the other hand, Haplogenis sp. was least at the site with sugar cane as the riparian vegetation. This might have been due to the use of fertilizers and other pesticides which had made the sites not habitable to these sensitive benthic macroinvertebrate species. This results confirm the findings of Moretti, Goncalves, Ligeiro, and Callisto (2007), Ligeiro, Moretti, Goncalves, and Callisto (2010), Goncalves, Rezende, Franca, and Callisto (2012) which also pointed out the Chironomidae sp. and Simulium sp. dominance associated with plant substrate in the decomposition process.

To establish statistically significant evidence of genuine clusters in Figure 6 'similarity profile' (SIMPROF) permutation test in Prime v6 was employed and results are presented in Figure 7. The permutation test for null hypothesis was that the benthic macroinvertebrate species abundance (*Megalagrion sp., Simulium sp., Chironomous sp.,* and *Haplogenis sp*.) do not differ among the nine sites of Kuywa River in multivariate structure.

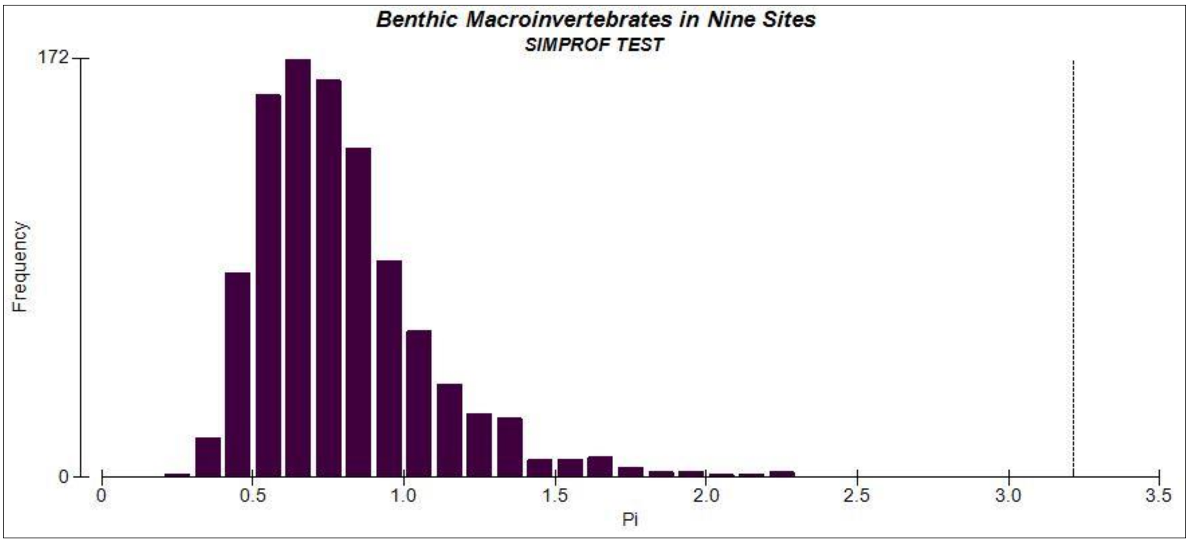


Figure 7: Simulated distribution for *Megalagrion sp., Simulium sp., Chironomous sp.,* and *Haplogenis sp.* abundance in the nine sampling sites of Kuywa River for the test statistic Pi under the hypothesis H_o of no site differences within each riparian vegetation cover: the observed Pi is 3.215 at 0.001 confidence level.

The results show a statistical significant clusters from each of a number of sites. SIMPROF (similarity profile) performed gave Pi=3.215 and p=0.001. This led to the rejection of the null hypothesis that benthic macroinvertebrate species abundance (*Megalagrion sp., Simulium sp., Chironomous sp.,* and *Haplogenis sp.*) do not differ among the nine sites of Kuywa River in multivariate structure. This implies that these four species of benthic macroinvertebrates in Kuywa River, their abundance depended much on the condition of riparian vegetation cover. The planted mature and natural conserved riparian vegetation cover supported more of these species compared to the sites with either sugarcane or young vegetation.

Loss of large woody debris reduces substrate for feeding, attachment, and cover; causes loss of sediment and organic material storage (Stauffer et al., 2000); reduces energy dissipation (Johnson, Breneman, & Richards, 2003); alters flow hydraulics and therefore distribution of habitats (Gurnell et al., 1995); reduces bank stability and community function as evidences by the MDS plot of *Megalagrion sp., Simulium sp., Chironomous sp.* and *Haplogenis species*. *Chironomous sp.* and *Simulium sp.* were more abundant at sites with either mature planted riparian vegetation or naturally conserved riparian vegetation. This may have been caused by

Simulium sp. getting enough food from the water column at these sites there is plenty of debris falling from the riparian vegetation into the water column. On the other hand the abundance of *Chironomous sp.* may have been attributed by the presence of wood debris in the river at natural conserved and mature planted vegetation sites to trap food particles (Johnson et al., 2003; Stauffer et al., 2000). Although some species were sensitive to percentage riparian vegetation, *Megalagrion sp.* and *Haplogenis sp.* were found to be tolerant to riparian vegetation absence (bare ground). The sites with minimal riparian vegetation cover had more of these species which may be as a result of these species having a wider ecological tolerance. The clusters for the tolerant and intolerant species appeared to be statistically significant ($Pi=3.215$, $p<0.001$) indicating that they did not form by chance. Similar studies have shown that land use that deprives a stream of riparian vegetation affects the attributes of aquatic macroinvertebrates (Corbi & Trivinho-Strixino, 2008; Tiago, Marcia, Carla, & Maria, 2015). A study carried out at Upper Wabash River in Indiana (Hrodey, Sutton, Frimpong, & Simon, 2009) revealed that intensive agricultural land use where riparian vegetation had been cleared led to remarkable changes in aquatic macroinvertebrate communities as well as to degraded water quality. Further, this study established that benthic macroinvertebrates responded negatively to increased habitat loss (Figure 6).

To assess the influence of riparian vegetation cover on sensitive orders, Ephemeroptera, Plecoptera and Tricoptera (EPT), indices were applied on the nine sampling sites and the results of the analyses are presented in Figure 8, 9 and 10. The species in the order of EPT are associated with pristine waters since they are pollution sensitive macroinvertebrates. Polluted water will have less EPT while less polluted will have more species richness and abundance.

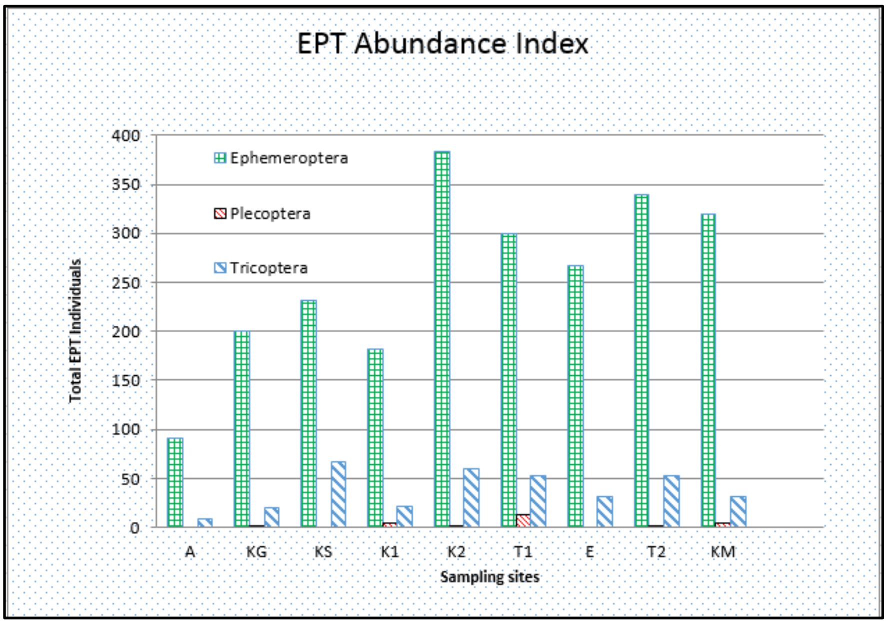


Figure 8: Ephemeroptera, Plecoptera and Tricoptera (EPT) abundance for the nine Kuywa River sites during the study period January-October, 2016.

A- Alumuli at Ngueno, **KG-** Kibingei at Daraja Mbili, **KS-** Kibisi at Matisi, **K1-** Kuywa at Kuywa market, **K2-** Kuywa at Nakoyonjo, **T1**- Teremi at Kimorong falls, **E-** Emia at confluence with Teremi, **T2-** Teremi at confluence with Emia, **KM-** Kimurio at Chepyuk

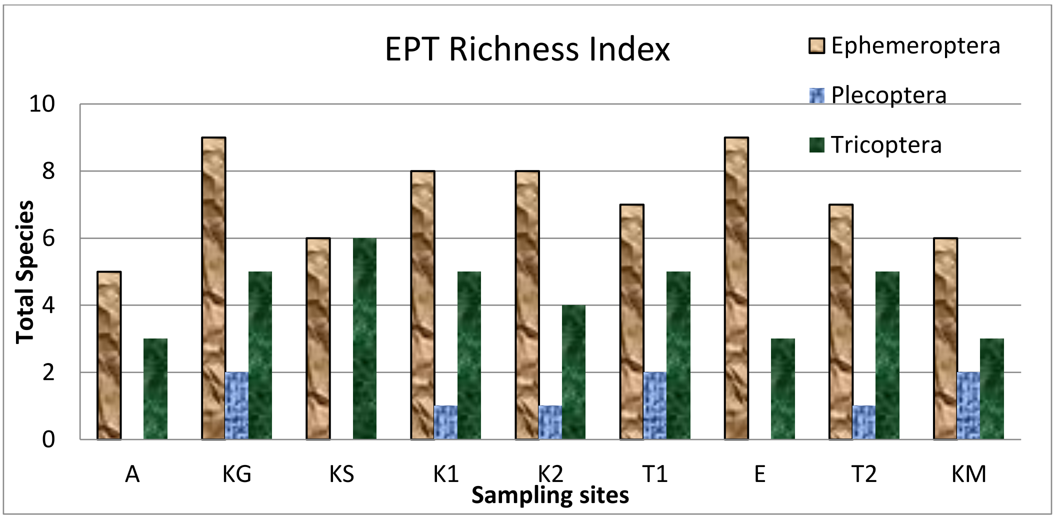


Figure 9: Ephemeroptera, Plecoptera and Tricoptera order richness index for the nine Kuywa River sites during the study period January-October, 2016.

A- Alumuli at Ngueno, **KG-** Kibingei at Daraja Mbili, **KS-** Kibisi at Matisi, **K1-** Kuywa at Kuywa market, **K2-** Kuywa at Nakoyonjo, **T1**- Teremi at Kimorong falls, **E-** Emia at confluence with Teremi, **T2-** Teremi at confluence with Emia, **KM-** Kimurio at Chepyuk

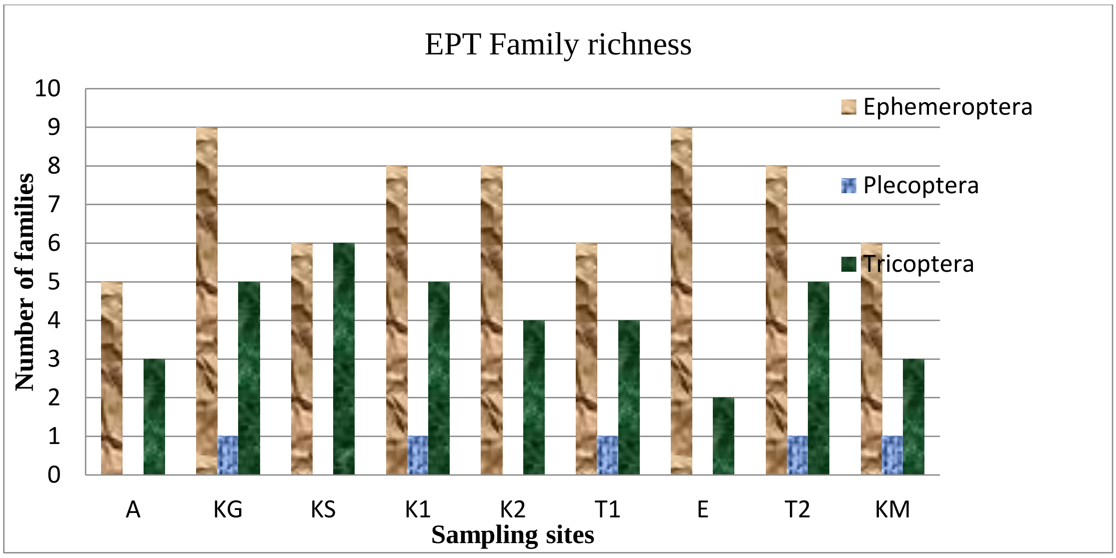


Figure 10: EPT family richness for the nine sample sites of Kuywa River with different riparian vegetation cover as collected between January to October, 2016.

A- Alumuli at Ngueno, **KG-** Kibingei at Daraja Mbili, **KS-** Kibisi at Matisi, **K1-** Kuywa at Kuywa market, **K2-** Kuywa at Nakoyonjo, **T1-** Teremi at Kimorong falls, **E-** Emia at confluence with Teremi, **T2-** Teremi at confluence with Emia, **KM-** Kimurio at Chepyuk

In the nine sites of Kuywa River, 2,687 (36% of individuals collected) EPT individuals were collected which were distributed in 22 genus (Table 7A-C). K2 was found to have the highest number of individuals in EPT, 444 (16.5% of total EPT) which comprised of 383 Ephemeroptera, 60 Tricoptera and only one Plecoptera (Figure 8). The reference (control) site KM, had 357 (13.2% of EPT) individuals made of 320 Ephemeroptera, 32 Tricoptera and 5 Plecoptera. It was unexpected that site A which had good riparian vegetation cover sustained the least number of EPT compared to other eight sites. The total individual in site A was 100 (0.04%) comprising of 91 Ephemeroptera, 9 Tricoptera and zero Plecoptera. Site K1 had second least number of EPT individuals, 208 (0.08%) comprising of 182 Ephemeroptera, 22 Tricoptera and 4 Plecoptera. K1 had mature planted riparian vegetation which appeared to be excellent in terms of vegetation cover, however, its upstream land use was intensive horticultural farming which may have affected the EPT abundance. T1 which was fenced off from animal interference had a fair representation of Ephemeroptera (300), Plecoptera (13) and Tricoptera (52) (Figure 8).

The sensitive EPT family of benthic macroinvertebrates have been used to indicate the health of rivers/streams. This study established that K2 and T2 had the highest percentage of EPT (16.5% and 13.0% respectively). This might have been due to the less disturbance at these two sites which had good riparian zone vegetation and less intensive agriculture on their catchment. The control site KM had also a comparable number of EPT to that of K2 and T2. Conversely, site A which had also good riparian zone vegetation had the lowest percentage EPT (0.04%), attributed to the effect of agricultural chemicals from the sugarcane plantation. As argued by Mason (2002), EPT are sensitive to disturbance and decrease with increase in nutrients levels. This was made more evident by the fact that sites A and E had no Plecoptera at all. Site E might have also missed Plecoptera due to high usage of fertilizers and pesticides on horticultural farms which were evident along the river. Site T1 had no grown vegetation but had a fair representation of EPT as a result of being fences off to eliminate the stress exerted by animals. Generally, the relative abundance of the intolerant group in all sites was believed to be influenced by organic matter and the availability of food for consumption. This finding agrees with Aura, Raburu, and Herrmann (2010), Mason (2002) and Orwa et al. (2013) who found similar results and attributed it to the influence of organic matter and food distribution of aquatic macroinvertebrates.

The EPT richness index in the nine sites ranged between 0 and 8 (Figure 10). T1 had a fair balance of the EPT richness (7, 2, 5 respectfully) compared to the other sites. The reference site KM had the richness of Ephemeroptera (6), Plecoptera (2) and Tricoptera (3) (Figure 10). Site A and E had no Plecoptera. In general there were more taxa of Ephemeroptera followed by Tricoptera and Plecoptera was rare. The same trend as that of EPT richness appeared in the family richness whereby Ephemeroptera was the richest in families followed by Tricoptera and then Plecoptera (Figure 11). Sites KG and E had the highest Ephemeroptera family richness (9) followed by K1, K2 and T2. The reference site had Ephemeroptera family richness of 6. Tricoptera families were more in KS (6) followed by KG, K1 and T2 each having richness of 5. There were no Plecoptera families in site A and E.

The distribution of EPT species to different sites varied with Ephemeroptera being the richest, followed by Tricoptera and Plecoptera least. This was comparable with similar studies in Kenya (example; Orwa, Raburu, Ngodhe, and Kipkorir (2014) and Oruta (2016)) who studied macroinvertebrates in adjacent streams (Kipkaren and Sosiani respectively). Furthermore, the EPT species richness was found to balance more in those sites with long coverage of riparian vegetation cover. The adjacent land use together with the riparian vegetation cover had great influence which led to site A, E and KS to lack Plecoptera species. Our result concurs with the one of Genito, Gburek, and Sharpley (2002) who established the decline of aquatic macroinvertebrates in intolerant taxa (e.g. EPT) with increased agricultural land cover. According to Belsel et al. (2000) the high complexity of riparian vegetation and its services to ecosystem lead to high colonization rates, which in turn support abundant and diverse aquatic macroinvertebrates in streams. In contrast, Sponseller et al. (2001) observe that the increased filamentous green algae production and the subsequent additional habitat it creates lead to a greater diversity of taxa in agricultural land use streams.

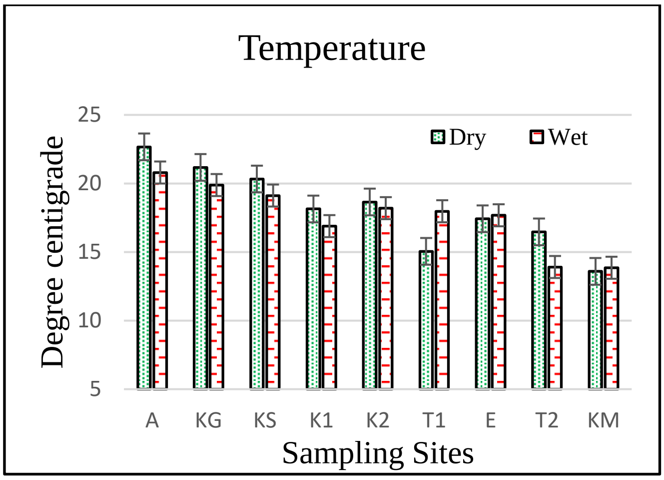
In summary, the study established that some sites had "Excellent" riparian vegetation cover while others had "Poor". *Hexatoma sp.* ($r=0.83$), *Belostoria sp.* ($r=0.73$) and *Simulium sp.* ($r=0.62$) were significant positively correlated to vegetation cover ($p<0.01$), while *Ariacalis sp.* ($r=-0.63$) and Notonectidae ($r=-0.69$) were significantly negatively correlated to riparian vegetation cover ($p<0.01$). Macroinvertebrate assemblage characteristics at different sites with different riparian vegetation cover indicated that site KG and T2 had highest species richness (35) while site E had the highest Shannon diversity index (2.55). ANOSIM hypothesis testing indicated variations between sites with 'Excellent', 'Good' and 'poor' riparian vegetation cover ($R=0.94$, $p<0.01$). SIMPER procedure indicated that *Simulium sp*. (12.85%), *Gompus sp.* (4.29%) and *Baetis sp.* (4.15%) contributed much to dissimilarity between sites with "Excellent" and "Poor" riparian vegetation cover. MDS configuration indicated for *Megalagrion sp.* and *Simulium sp*. indicated that sites with mature planted riparian vegetation had the same species characteristics like those in natural conserved riparian vegetation cover. SIMPROF test indicated that MDS clusters generated for the nine sites were statistically significant ($Pi=3.215$, $p<0.001$). For intolerant species (EPT), the percentage was reasonably high (36% of individuals collected) with K2 contributing the greatest percentage (16.5%) and site A lowest (0.04%). Site T1 had EPT ratio of 7:2:5 which was near to that of control site KM (6:2:3).

4.4 Temporal variation of water quality parameters and benthic macroinvertebrate assemblage characteristics in the Kuywa River

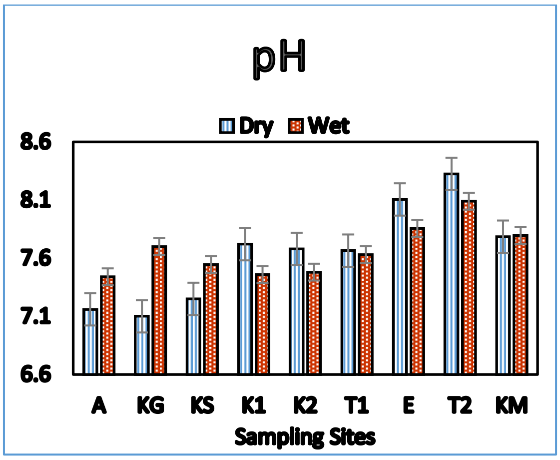
As noted from the previous section, most aquatic macroinvertebrates reside in the benthic habitat for at least part of their life, relatively immobile, and very sensitive, therefore any disturbances in aquatic environment may cause them to disappear or reduce in diversity. This section explores temporal variation of water quality parameters in Kuywa River during the study period, then benthic macroinvertebrate assemblages before combining them to establish their relationship.

4.4.1 Temporal patterns in water quality parameters in the Kuywa River

Temporal patterns of water quality parameters were analyzed for both dry and wet seasons in the nine sites of Kuywa River. Figure 11A-M provides a presentation of the summarized outcome.



A



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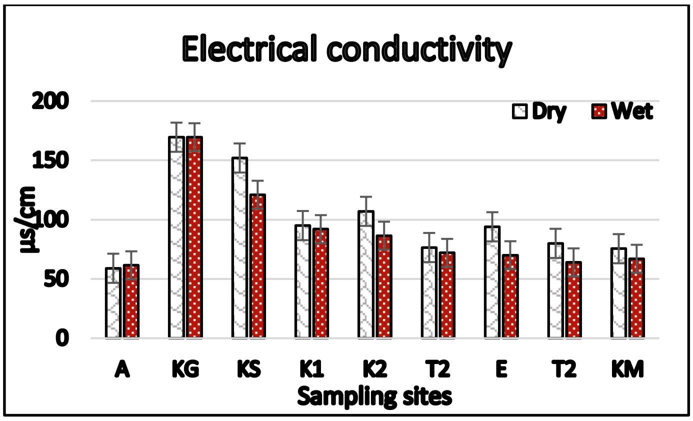
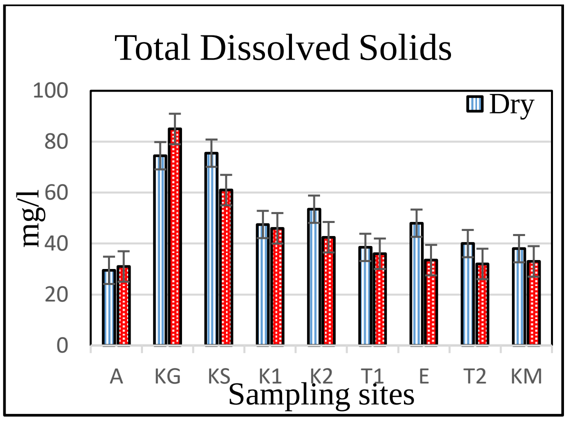
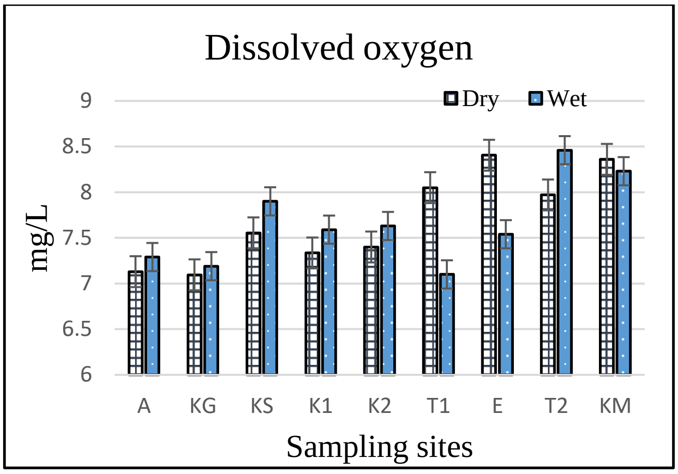


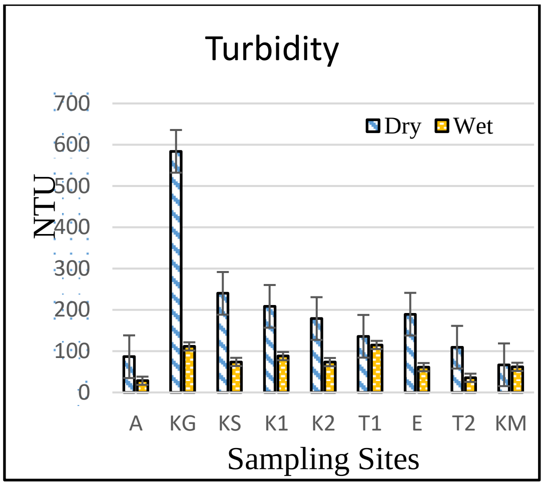
C



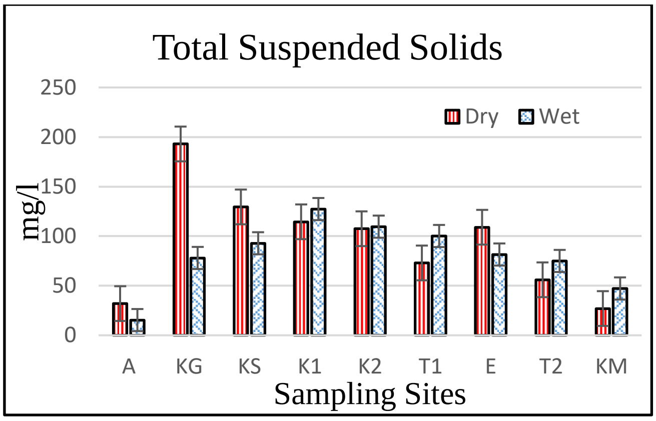
D


Dissolved oxygen
Dry
Wet
mg/L
9
8.5
8
7.5
7
6.5
6
A KG KS K1 K2 T1 E T2 KM
Sampling sites

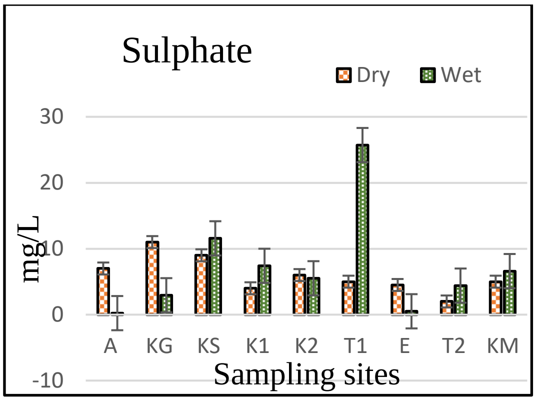
E


Turbidity
Dry
Wet
NTU
700
600
500
400
300
200
100
0
A KG KS K1 K2 T1 E T2 KM
Sampling Sites

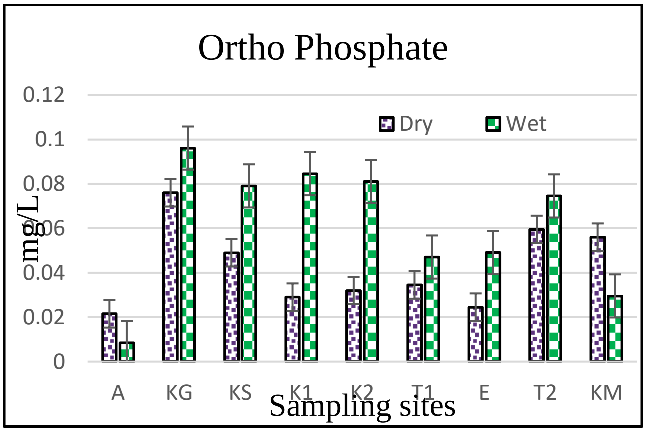
F


Total Suspended Solids
Dry
Wet
mg/l
250
200
150
100
50
0
A KG KS K1 K2 T1 E T2 KM
Sampling Sites

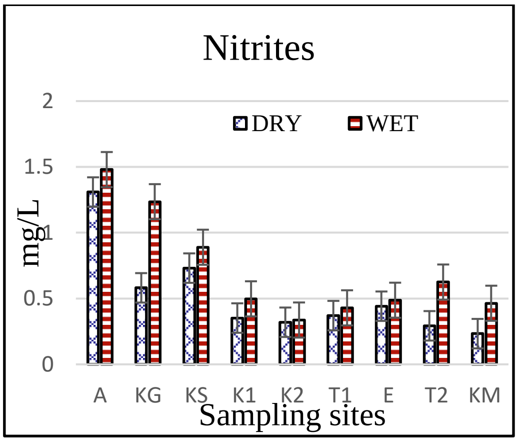
G


Sulphate
Dry
Wet
mg/L
30
20
10
0
-10
A KG KS K1 K2 T1 E T2 KM
Sampling sites

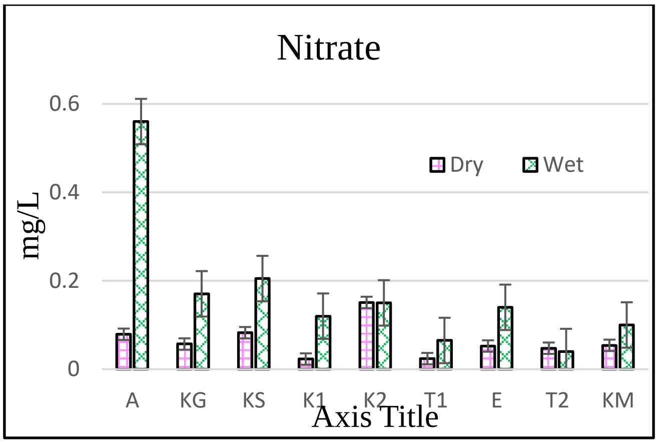
H


Ortho Phosphate
Dry
Wet
mg/L
0.12
0.1
0.08
0.06
0.04
0.02
0
A KG KS K1 K2 T1 E T2 KM
Sampling sites

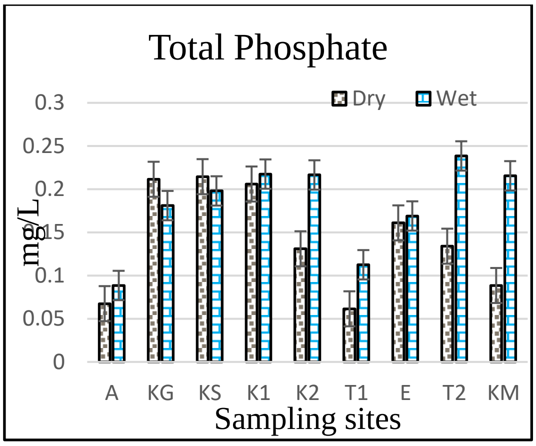
I


Nitrites
DRY
WET
mg/L
2
1.5
1
0.5
0
A KG KS K1 K2 T1 E T2 KM
Sampling sites

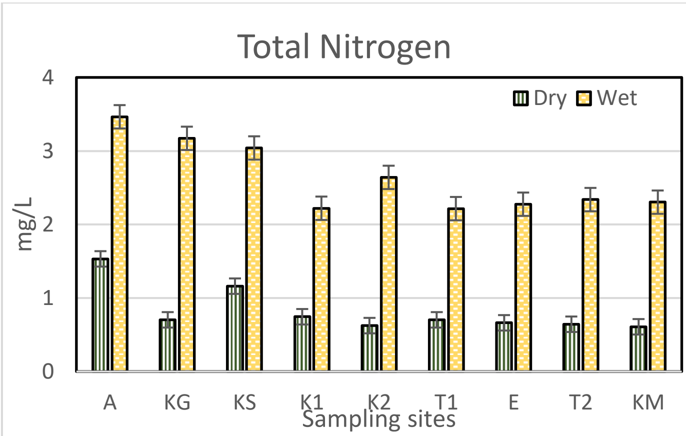
J



K



L



M

KEY
A - Alumuli at Ngueno
KG – Kibingei at Daraja Mbili
KS – Kibisi at Matisi
K1 – Kuywa at Kuywa market
K2 – Kuywa at Nakoyonjo
T1 – Teremi at Kimorong falls
E – Emia at confluence with Teremi
T2 – Teremi at confluence with Emia
KM – Kimurio at Chepyuk

Figure 11 A-M: Seasonal comparison of water quality parameters (Temperature, pH, Electrical conductivity, Total dissolved solids, Dissolved oxygen, Turbidity, Total suspended solids, Sulphate, Orthophosphate, Nitrites, Nitrates, Total phosphate and Total nitrogen) variables in the nine sampling sites of Kuywa River in 2016

In-stream temperature was found to be high during the dry season compared to the wet season as expected except site T2 and K2 which had higher temperatures during the wet season (Figure 12A). K2 had temperature of 19.2^{o}C during the wet season and 18.7^{o}C during the dry season. On the other hand, T1 had 16.6^{o}C during the wet season and 15.1^{o}C during the dry season. Differences in temperature determines the oxygen concentration in water and the body metabolism for aquatic biota. Lewis (2000) states that, the oxygen retention capacity of tropical water bodies is lower at higher temperatures as compared with lower temperatures. The seasonal differences are due to sunshine intensity reaching the earth surface at different seasons. Solar radiation striking water's surface also contributes energy in the form of heat. The lower temperatures in site T1 and K2 during the dry season may have been attributed by the effect of riparian zone vegetation upstream of these sites, which provided a shading effect in the river. Other studies have indicated the moderation of stream water temperature by riparian vegetation cover (Barton, Tailor, & Biette, 1985; Monoury et al., 2014). Density of riparian canopy is one of the most critical factors in determining the heat input in a given stream. The upstream length of forested channel, riparian vegetation width and density, canopy opening, and groundwater influence the contribution of heat to a stream (Figure 11A)

Although both wet and dry seasons indicated neutral to alkaline state of the nine sites of Kuywa River, sites E, T2 and KM had lower values of pH during the wet season (7.9, 8.0, and 7.4 respectively) compared to dry season (8.1, 8.3,and 7.8 in that order) (Figure 11B). The rest of the sites had higher values during the wet season. It was worthy nothing that it was the control site KM which had lowest pH value for the wet season. The local geology of the area may affect the pH values of a stream. At the same time the agro-based chemicals used in agricultural farms may be washed into the stream during the wet season alongside with sediments, thus increasing acidity of river water during the low flows. These human activities may have contributed to sites A, KG, KS, K1 and K2 having low values of pH during the dry season since they are surrounded by intensive and plantation farming. Site T1, E, T2 and KM which had adequate riparian vegetation experienced lower pH values. This may have been attributed by the processes of photosynthesis and decomposition determine the spatial and temporal distribution of inorganic carbon and hence pH. The consumption of CO_2 by photosynthesis process and production of CO_2 by respiration process of aerobic bacteria increase the concentration of H^+ which drops the pH.

Electrical conductivity can serve as an indicator of non-point source inputs, including sediments, fertilizers, and pesticides (Roy, Rosemond, Paul, Leigh, & Wallace, 2003). Half of the sites indicated seasonal variations in electrical conductivity in the Kuywa River, with higher values during the dry season. These sites with higher values in dry season included KS (dry=152µS/cm, wet=121µS/cm), K1 (dry=95µS/cm, wet=79µS/cm), K2 (dry=107µS/cm, wet=77.5µS/cm) and E (dry=94µS/cm, wet=64µS/cm) (Figure 11C). Electrical conductivity is an indirect measure of the total concentration of ions in water which means that the four sites indicated above had more concentration of ions during the dry season. In streams, ions occur naturally in the water as a result of the local geology and subsequent geochemical processes. However, the higher levels detected in streams surrounded by increasing land use suggest an anthropogenic effect. Electrical conductivity in the present study was generally low during the wet season as a result of runoff dilution. Increased electrical conductance in agricultural catchments is not well understood, but has been attributed to potential diffusive sources from agricultural fields, including fertilizer use and livestock waste and the exposure of fresh soil to weathering through tilling practices (Collins & Jenkins, 1996; Herlihy, L., & Johnson, 1998; Ometo et al., 2000). In the present study, only site T1 had higher values of electrical conductivity for the wet season than dry season. This was consistent with Rose (2002) who established that reduced baseflow in a stream leads to concentrated ions in water thus increasing conductance. Other studies have established low electrical conductivity during the high flows of rivers (Kilonzo et al., 2014; Odume et al., 2012).

All the nine sites of Kuywa River had higher turbidity values for the dry season compared to those of wet season (Figure 11F). The turbidity of the river is greatly affected by hill-side erosion from agricultural farms, livestock movement and erosion from earth roads (Sheldon & Fellows, 2010). The high turbidity values during the dry season may have been caused by animals being waters in the stream as well as some sites used for sand harvesting (e.g. at site

KG). This may be inferred due to the fact that on the dry season, base flow is largely maintained by groundwater inputs from the headwater streams and springs. Thus the stream water is expected to be clear unless stirred up by people and livestock. Mathooko & Mavuti (1992) established that even during the dry season, animals may disturb stream water which increases turbidity. Downstream is unlikely to be loaded much with sediments as it would be during the wet season.

Total suspended solids had a mixed trend whereby the sites which were from the upper catchment had higher values for wet season while those at the lower catchment had higher values for the dry season (Figure 11G). Site A, KG, KS, K1 and E had higher TSS values during the dry season (32mg/l, 193mg/l, 129mg/l, 114mg/l and 109mg/l respectively) compared to wet season (15mg/l, 78mg/l, 92mg/l, 104mg/L, and 57mg/l respectively) (Figure 11G). The increase in the TSS concentration during wet season illustrates the influence of the catchment on the water body's water quality parameters. This study is consistent with Kemdirim (2005) for which storm-runoff is recognised as the major source of solid suspended materials in the water bodies. It was expected that because of the extended calm period during the dry season, the suspended solids tend to settle (Rangel-Peraza, Anda, Gonzalez-Farias, & Erickson, 2009).

The nutrient concentration levels are very precipitation sensitive with the lowest recorded in the nine sites of Kuywa River corresponding with dry months and the highest with the wet months. The present study indicated that nutrient concentrations in the nine sites of Kuywa River differed between dry and wet seasons (Figure 11H). Wet season had higher values of sulphate in the six sites (KS, K1, K2, T1, and KM) out of nine. The remarkable high values of sulphate in the wet season was observed at site K2 (wet=15.6mg/l, dry=6.0mg/l) and T1 (wet=16.6mg/l, dry=5.0mg/l). Site A had insignificant concentration of sulphate (0.2mg/L) in the wet season. This is attributed by the fact that in wet months runoff from the farms carry nutrients along with them, especially if the farms are not well managed. As noted by Wilson et al. (2008), in dry season, nutrients in the water are the remnants from the wet season plus those transported in disturbed sediments (may be by livestock).

Two sites (A and KM) had higher values of orthophosphorus during the dry season while the rest of the sites had higher values in the wet season. In general for both wet and dry seasons the concentration of orthophosphate in water increased downstream along the Kuywa River except for site A which was located on a small stream joining the Kuywa River (Figure 11L). The sites which had higher values of orthophosphate were those surrounded by intensive farming. Intensive farming require the input of large quantities of phosphate fertilizers which find their way into water courses during top-dressing operations and as runoff. This is consistent with Townsend, Hildrew, and Francis (1983) who argue that streams passing through intensive farming have higher concentrations of phosphorus. The increase of phosphate downstream may have been attributed by the additive effect by the increased catchment area draining into the stream. Hunsaker and Levine (1995) analysed the relationship between land use and water quality in Wabash catchment in Illinois, USA and found that as the proportion of agriculture in a catchment increased so did phosphorus and nitrogen concentration.

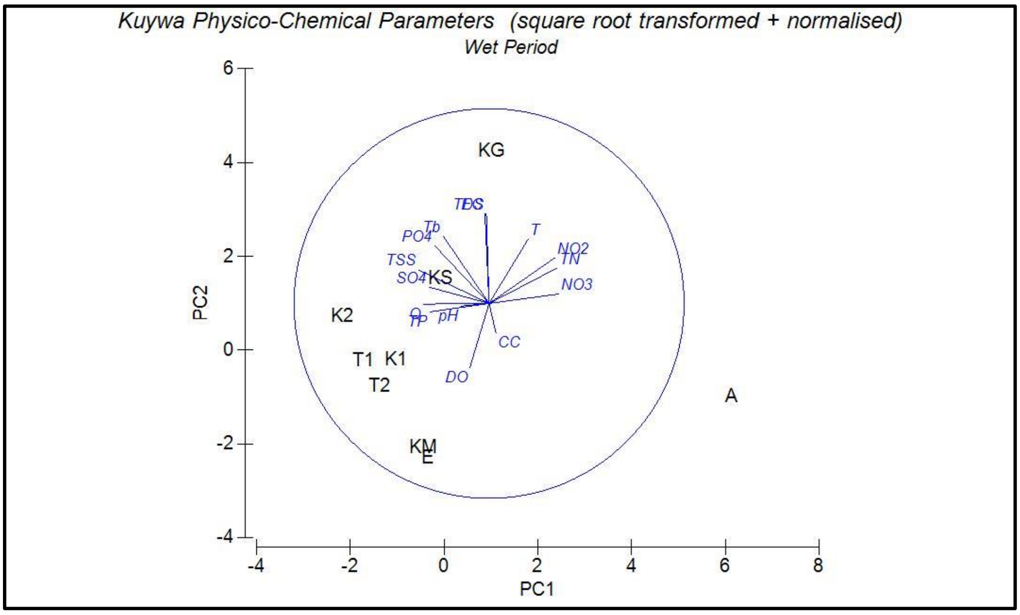
In this study, it was clear that in both dry and wet seasons nitrite (NO_2) concentration increased downstream of Kuywa River (Figure 11J). The highest concentration was observed at site A (wet=1.5mg/l, dry=1.3mg/l) which was located on a small stream traversing through the sugarcane plantation. The control site KM which was located near the conserved forest had the lowest nitrite concentration (wet=0.3mg/l, dry=0.2mg/l). The rest of the sites had values in between the lowest and highest. Site A had extremely high nitrates (0.56mg/l) in the wet season compared to the other sites. It was noticeable that wet season had higher nitrate concentrations in the Kuywa River compared to the dry season (Figure 11K). The increase in concentration downstream may be attributed by the use of inorganic fertilisers in agricultural farms. During the wet season the runoff from the farms may be transporting it to the streams. This findings are consistent with Kilonzo (2014). While studying on Mara River, established that sites located closer to the forested areas had the lowest temporal variations, while the stations located downstream in the agricultural and densely populated areas had both highest variability and highest values of nitrites and nitrates.

Six sites of Kuywa River (A, K2, T1, E, T2 and KM) had higher values of total phosphorus in the wet season. Only KG, KS and K1 had higher values during the dry season (Figure 11L). Unexpectedly, the control site KM had highest total phosphorus (0.3mg/l) in the wet season compared to other eight sites. The presence of high total phosphorus concentration in the Kuywa River could have different sources which may include the accumulation of sediments dragged through erosive processes in the upper catchment and from runoff during the rainy season, containing agrochemicals from horticultural farms. This findings were consistent with (Roberto, Jose, & Fernando, 2009) who attributed the presence of sulphates and phosphorus to sediments and erosive processes within the catchment of streams.

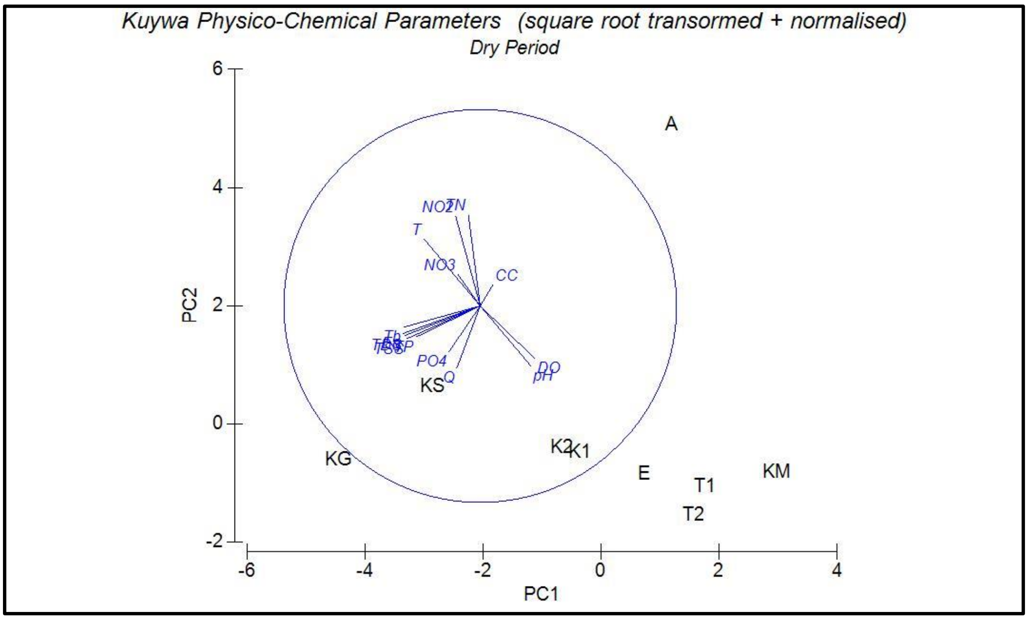
Total nitrogen similarly exhibited high values during the wet season except for site K2 (wet=1.2mg/l, dry=1.4mg/l) and T1 (wet=1.2mg/l, dry=1.5mg/l) (Figure 11M). More so, the wet season had an increase in total nitrogen concentration downstream of Kuywa River while dry season had no pronounced trend. During the wet season site A had the highest concentration (1.8mg/l) followed by KG (1.6mg/l) and KS (1.6mg/l) (Figure 11M). The control site KM had a concentration of 1.4mg/L. On the other hand, KS still maintained a higher concentration of total nitrogen (1.6mg/L) together with A (1.5mg/l). Site KM which was just outside the conserved forest had a direct anthropogenic impacts. There was a higher variability of TN between the seasons at site KM, KG and K1 although all these sites had good riparian vegetation cover. This may have been caused by the presence of large numbers of animals that drink directly in the river as well by irrigated vegetable farms in the vicinity of KG. This findings are similar to those of Kilonzo (2014) who established a high TN and TP variability between wet and dry seasons and attributed it to the animal disturbances and horticultural practices.

Generally, in the present study of the Kuywa River the values of total dissolved solids during the dry season were higher than those of wet season except at KG (wet=85mg/l, dry=74.5mg/l) (Figure 11). In the nine sites of Kuywa River, the study established an increase in total dissolved solids down-stream both in the wet and dry seasons (Figure 11D). Generally, dry season had higher concentrations of total dissolved solids compared to the wet season except for site KG (wet=85mg/L, dry=74mg/l). The control site had almost the same concentration of total dissolved solids for both seasons (wet=37mg/l, dry=38mg/l). Generally, the river appears to have distinct physico-chemical characteristics in the dry and wet seasons with more influence of point source contamination in the wet than dry season. For example, it is warmer over the dry season than wet season. In both seasons, there is a general trend of increasing temperature downstream. Other water quality parameters also variety considerably (Figure 11A-M).

To explain the variance-covariance structure of water quality parameters at the nine sampling sites of Kuywa River in the dry and wet seasons through linear combinations, Principal Component Analysis (PCA) was used. PCA assisted in explaining the maximum amount of variance with the fewest number of principal components. Their results are presented in Figure 12 (also refer to Appendix 2 for detailed values). Longer vectors in the plot indicates that that variable was important in differentiating the nine sites at that particular season.



(A)



(B)

Figure 12A-B: Principal Components Analysis (PCA) of water quality parameters (square root transformed) for nine sites in Kuywa River during the dry period of January and August 2016 and Wet period of May and October, 2016. The circular line represents the circle of correlations and the vectors the eigenvalues of each variable. A short vector means that this particular variable was not well represented in the first two dimensions and that the correlation with the other variables was low.

Temp - temperature, Ec - electro conductivity, TDS - total dissolved solids, DO - dissolved oxygen, Turb - turbidity, Sulp - sulphates, Phos - ortho phosphorous, NO2 - nitrites, NO3 - nitrates, TP - total phosphorus, TN - total nitrates and Q - discharge.

A- Alumuli at Ngueno, **KG-** Kibingei at Daraja Mbili, **KS-** Kibisi at Matisi, **K1-** Kuywa at Kuywa market, **K2-** Kuywa at Nakoyonjo, **T1**- Teremi at Kimorong falls, **E-** Emia at confluence with Teremi, **T2-** Teremi at confluence with Emia, **KM-** Kimurio at Chepyuk

The results show that the first three PCA axes summarising physico-chemical parameters variations explained for dry season 40%, and 28.3% and wet season 41.2%, and 26.8% (PC1 and PC2) of the variance, respectively (eigenvalues: dry season 5.6, 3.96 wet season 6.18, 4.02 respectively) (Figure 12).

PC1 in the nine sampling sites was mostly loaded during dry season on electro-conductivity, turbidity, total suspended solids, and total dissolved solids and wet season on nitrates, nitrites, total nitrates, total phosphorus, and discharge. Thus in dry season PC1 may be named for physical variables and wet season PC1 as chemical variables. PC2 dry season loaded on nitrites and total nitrates while wet season loaded on total dissolved solids and dissolved oxygen. This implies that in dry season PC2 was loaded with chemical variables and wet season PC2 loaded with physical variables. This finding implies that during the dry season the nine Kuywa River sites were very different in terms of electro-conductivity, turbidity, total suspended solids and total dissolved solids. This may be attributed to the less materials from the catchment reaching the river as compared to the wet season. In the wet season, nutrients and dissolved oxygen varied greatly between the sites. This was attributed to the runoff from the catchment which transported both organic and inorganic materials and finally leading to flourishing of instream algae which consumes oxygen from the water column. The findings are consistent to those of Kilonzo (2014), while studying Mara River established that turbidity of river water was higher during the wet season and attributed it to erosion of the earth roads and hill slope cultivation of farms. Kilonzo (2014) further established that the lower conductivity of Mara River during the wet season was attributed to the dilution effect of the high flows.

The PCA axis 1 and axis 2 accounted for a cumulative of 68.3% in the dry season and 68% wet season of the total variations. The PCA, therefore, revealed that axes 1 and 2 could explain more than half of the variations among the sites in accordance with the measured water quality parameters, which is an indication of a good ordination (Kilonzo et al., 2014; Legendre & Gallagher, 2001). PCA separated site A and KG from the rest of the seven sites for both dry and wet seasons. Separation of site A with PC1 dry season being physical variables and wet season Nutrient (chemical) variables can be explained through its catchment activities. Site A was located in the nuclear farms of the sugarcane plantation, where fertilizers and other pesticides are applied extensively. During the rainy season these chemicals are transported to reach the stream. On the other hand, during the dry season, site A there is less nutrients being transported thus the physical variables become the determinant, especially as the sugarcane remnants are scattered in the stream. Studies carried out by Astudillo, Novelo-Gutie´rrez, Vazquez, and Garcia-Franco (2016) at Mexico established increased suspended solids and TDS in streams where harvesting is taking place. The separation of site KG may be attributed to the eucalyptus plantation along the river course which minimizes the undergrowth vegetation and macrophytes to bio-accumulate the nutrients. Furthermore, eucalyptus tree leaves do not decompose as fast as those from indigenous trees which have soft surface and tissues and fever rapid colonization and degradation by microorganisms and invertebrates (Gracia & Canhoto, 2006; Garcia, Pardo, & Richardson, 2014). More so, site KG had a catchment recently been invaded by sugarcane small scale farms.

Electro conductivity, turbidity and total suspended solids loads PC2 with less significance during the wet season due to high dilution of the runoff. In dry season total nitrates and nitrates become less important to take PC2 since they are only transported in the sediments. The sites with higher percentage of canopy cover may have also grouped together due to the role played by shading especially in the dry season. Dissolved oxygen only contributed to PC2 significantly during the wet season. This must have been the result of mixing of water caused by a significant drop in altitude between the stations (Masese et al., 2009). Furthermore, wet season has more water to mix than dry season. Temperature played a great role in discriminating the nine sites during the dry season. It had no influence in the wet season. Vegetation cover limits solar radiation reaching the water thus contributing to minimal fluctuations of temperature.

4.4.2 Temporal patterns in benthic macroinvertebrate assemblage in the Kuywa River

To establish the temporal patterns in macroinvertebrate assemblages in Kuywa River, univariate diversity measures (Abundance, richness, evenness and diversity) were used. Table 13 provides a summary of results and analyses for both dry and wet seasons.

Table 13: Total species, abundance, species richness index, species evenness index and Shannon diversity index the nine sites of Kuywa River sampled both in dry and wet seasons in 2016

	Total species (S)		**Abundance (N)**		**Species richness Index (d)**		**Species evenness Index (J')**		**Shannon diversity Index (H')**	
	dry	**wet**	**dry**	**wet**	**dry**	**wet**	**dry**	**wet**	**dry**	**wet**
A	15	18	60	647	3.4	2.6	0.8	0.4	2.1	1.3
KG	15	25	103	209	3.0	4.5	0.7	0.7	2.0	2.1
KS	18	20	144	351	3.4	3.2	0.7	0.8	2.1	2.3
K1	16	21	160	1696	3.0	2.7	0.7	0.2	2.0	0.6
K2	23	23	791	235	3.3	4.0	0.5	0.8	1.5	2.4
T1	16	23	234	373	2.7	3.7	0.6	0.8	1.7	2.4
E	22	23	441	403	3.4	3.7	0.7	0.8	2.1	2.4
T2	22	22	211	332	3.9	3.6	0.7	0.7	2.1	2.2
KM	15	22	186	866	2.7	3.1	0.8	0.5	2.2	1.7

S- Richness index; **N-** Abundance index; **d-** Margalef richness; **J'-** Plelou's evenness; **H'-** Shannon index; **E_H-** Shannon evenness; **1-λ-** Simpson diversity.

A- Alumuli at Ngueno, **KG-** Kibingei at Daraja Mbili, **KS-** Kibisi at Matisi, **K1-** Kuywa at Kuywa market, **K2-** Kuywa at Nakoyonjo, **T1-** Teremi at Kimorong falls, **E-** Emia at confluence with Teremi, **T2-** Teremi at confluence with Emia, **KM-** Kimurio at Chepyuk

The results show that a total of 2,330 and 5,112 individuals were collected for dry and wet seasons respectively from the nine sites of the Kuywa River (Table 13). The benthic macroinvertebrates during the wet season belonged to 46 species of 12 orders, while dry season they belonged to 42 species from 13 orders (Table 13). During the dry season the most common genus were *Baetis sp.* (Ephemeroptera) (34%) and *Simulium sp.* (Diptera) (21%) while wet season was dominated by *Simulium sp.* (51%), Baetis (15%) and *Chironomous sp*. (Diptera) (8%).

According to macroinvertebrate assemblages, the result indicated that there was an on-going influence of pollution on the biota communities in the Kuywa River. The higher numbers of individuals during the wet season may be attributed to the dilution effect of increased discharge in rivers (Ramirez & Pringle, 2001). Excessive nutrients in the river, depletes oxygen from the water column thus reducing fauna (Sheldon et al., 2012). Taxonomic composition of the nine sites varied with seasonal variation mostly due to variations in Ephemeroptera, Diptera and Tricoptera. Taxonomic variations were related to DO, PO_4, NO_2, NO_3 and TP which increase due to anthropogenic activities in the catchment and less delusion during the dry season. Poor water quality with high concentrations of pollutants endangers many aquatic species, reducing biodiversity to only tolerant species. Pollution causes very low DO in water. High nutrients (PO4, NO2, NO3, TP and TN) pollution can obviously result in the decrease of biodiversity. Xu, Wang, Duan, and Pan (2014) studying in 49 Chinese rivers established that taxa richness decreases drastically with TN increasing. Other studies have also found that human related activities impacted on macroinvertebrate assemblage structure and composition in tropical stream, e.g., Ndaruga et al. (2004) in Kenya, Yule, Boyero, and Marchant (2010) in Indonesia and Helson, Williams, and Turner (2006) in Tridat. Change in flow have also been associated with changes in the water quality regime of the streams (e.g. (Brett et al., 2005; Hatt, Fletcher, Walsh, & Taylor, 2004; Wallace, Croft-White, & Moryk, 2013).

At the nine sampling sites, it was observed that there were more species in the wet season compared to the dry season. The same trend was also observed for the total individuals sampled with seven sites having higher individuals in the wet season than dry except for site A and K2 (site E dry=441, wet=403 and K2 dry=791, wet=235) (Table 13). Apart from site A which had a remarkable higher species richness in dry season (dry=3.4, wet=2.6) the eight sites showed higher richness during the wet season. Sites A, KG, KS, K1 and KM had a higher species evenness during the dry season compared to the wet season unlike sites K2, T1 and E which indicates higher evenness in wet season (Table 13). Site T2 showed no response to seasons in terms of species evenness (J'=0.7). For the Shannon diversity, sampling site A, K1 and KM had higher values in dry (2.1, 2.0 and 2.2, respectively) season compared to wet season (1.3, 0.6 and 1.7, respectively) but the rest of the sites had higher values for wet season. Temperature is the most apparent factor which affects the seasonal cycle and abundance of aquatic macroinvertebrates (Sharma & Chowdhary, 2011). It is the shallowness of site A that its water gets directly affected by atmospheric temperatures. It is well known that the shallower the water body, the more quickly it will react to the change in the atmospheric temperature (Sharma & Chowdhary, 2011). This may be one of the reasons why site A had different macroinvertebrate structure than other sites in Kuywa River.

The domination of *Simulium sp*. (Diptera) was evident in Kuywa River, where more than 60% of the individuals belonged to the order during the wet season. However, in the dry season, although the macroinvertebrates were dominated by Diptera the percentage dropped to below 35%. *Baetis sp*. (Ephemeroptera) was found to follow Diptera order in abundance. This finding was consistent with other studies carried out in tropical streams, mainly in Kenya. Mathooko and Mavuti (1992) while studying Mount Kenya streams established that the macroinvertebrates were dominated by *Baetis sp.* (Ephemeroptera) and *Simulium sp.* (Diptera). Studies carried out by Kibichii, Shivoga, Muchiri, and Miller (2007) in Njoro Stream, Kenya, found out that *Baetis sp*. and *Simulium sp*. composed of 69% by numbers of all benthic taxa identified. Moiben River which is the adjacent catchment to Kuywa was studied by Masese et al. (2009) and Diptera and Ephemeroptera found to account for more than 69%. The dry season had a marked changes in relative abundance of other opportunistic taxa reduced the percentage especially of Ephemeroptera which is more sensitive to human perturbation. In the dry season, Ephemeroptera were replaced by more tolerant species such as *Chironomous sp., Hydropsyche sp., Gomphus sp.,* and *Oligochaeta*. The less sensitive species are associated to organic pollution which in this catchment come from agricultural farms eroded during the rainy season, and more so, from excretion by livestock in the riparian areas (Buss, Baptista, Silveira, Nessimian, & Dorville, 2002). The control site had also disturbance from livestock, as there was a watering site about 500m upstream and quite a number of wild animals in the national park, about 1km upstream.

The temporal difference in species richness between the nine sites could be attributed to difference in vegetation cover which had an impact on temperature and nutrient levels. For instance, the lower temperature at site T2 compared to E which was on a tributary 100m apart, could be explained by high vegetation cover, which provided a shading effect to moderate water temperature. This was evidenced by T2 having species richness of 3.9 while E had 3.4. The control site (KM), which was well covered by vegetation had the lowest species richness (2.7) attributed by minimal macrophytes in the stream to remove nutrients emanating from livestock excretion upstream. Studies carried out by Orwa et al. (2013) at Nyando wetland, Kenya, established that sites which were covered by Cyperus had a lower temperature and nutrient levels compared to open sites. Chapra (1997) established that water temperature has a direct impact on anabolic and catabolic processes that occur in water bodies, and also influence concentration of dissolved gases. The maximum dissolved oxygen concentration in the surface waters in the nine sampling sites was recorded during the cold and wet season. This is consistent with the study of Lewis (2000) who stated that the oxygen retention capacity of tropical water bodies is lower at higher temperatures, as compared with lower temperatures. Studies elsewhere have detected the impact of cattle, especially at the watering points (Davies-Colley, Nagels, Smith, Young, & Phillips, 2004; Miller, Chanasyk, Curtis, Entz, & Willms, 2010; Owens, Edwards, & VanKeuren, 1996) and success in restoration has not been easy for some water quality parameters (Miller et al., 2010). Further, Kilonzo et al. (2014) established that sites in agricultural areas with well protected banks and vegetation cover have a higher macroinvertebrate diversity comparable to those in forested catchments.

Stable stream flows over the dry season favoured colonization (Makoba et al., 2008) of a number of species leading more evenness compared to the wet season. On the other hand, some benthic macroinvertebrate species such as dipterans lack specialized attachment structures and mechanisms for holding on in a strong current experienced in the rainy season. This could be the reason of having very low values of species evenness at some sites especially A and K1 which was prone to flooding, owing to clear-cut of sugar cane during harvesting with the resultant increased surface runoff. Sanchez-Arguello, Cornejo, Pearson, and Boyero (2010) found higher taxonomic richness and evenness in a Tropical Panamanian stream which they associated with variations in Diptera, Ephemeroptera, Coleoptera, Odonata and Tricoptera all favoured by dry season.

According to Gjerlov, Hildrew, and Jones (2003), macroinvertebrate communities generally react to seasonal variations in stream flow with a reduction in density and taxonomic richness. The effect for example of flash flood might be felled in small streams but short-lived, because many taxa of benthic macroinvertebrates have high resilience to stress (Adámek et al., 2016). This accounted for the higher values of Shannon diversity observed in wet season for sites KG, KS, K2, T1, T2 and E. The short time delay between flash flood and sampling of benthic macroinvertebrate (4-7 days) were sufficient for recovery of the fauna assemblage whether by re-colonization or re-appearance of hiding macroinvertebrates.

To investigate the effect of seasonal variability on sensitive species, the Ephemeroptera, Plecoptera and Tricoptera (EPT) were used. The more abundant these species are, the better is the water quality. However their diversity and richness which are considered later are indicative of the water quality. The distribution of these species are summarized in Table 14.

Table 14: EPT abundance index for the nine Kuywa River sites sampled in dry and wet seasons between January to October, 2016

	Dry			**Wet**		
	Ephemeroptera (E)	**Plecoptera (P)**	**Tricoptera (T)**	**Ephemeroptera (E)**	**Plecoptera (P)**	**Tricoptera (T)**
A	24	0	0	67	0	8
KG	78	0	0	122	1	19
KS	69	0	10	163	0	52
K1	98	0	6	85	4	11
K2	319	0	22	64	0	38
T1	157	2	8	143	0	42
E	111	0	16	156	0	14
T2	157	2	7	182	0	45
KM	71	0	18	249	1	14

A- Alumuli at Ngueno, **KG-** Kibingei at Daraja Mbili, **KS-** Kibisi at Matisi, **K1-** Kuywa at Kuywa market, **K2-** Kuywa at Nakoyonjo, **T1-** Teremi at Kimorong falls, **E-** Emia at confluence with Teremi, **T2-** Teremi at confluence with Emia, **KM-** Kimurio at Chepyuk

Table 14 shows that there is a great influence of human activities on the quality of water in the Kuywa River both in dry and wet seasons, evidenced by only two sites having Plecoptera order in both seasons. Generally, Ephemeroptera dominated the EPT group followed by Tricoptera. In dry season, Ephemeroptera were found to be more in site K1, K2 and T1 while the rest of the sites had more individuals in the wet season. For site comparison, site K2 had the highest Ephemeroptera while site A had the lowest (Table 14). The sediment deposits in the river might have contributed much to the assemblage of sensitive species in the nine sites for both dry and wet seasons. In dry season the sediment deposits in the river releases nutrients into the water while in the wet season they reduce habitat for macroinvertebrates. The sediment deposits may have led to increased tolerant species in the expense of intolerant. Walters, Leigh, and Bearden (2003) found that there was a decrease in endemic fish species of the south-eastern United States and an increase in cosmopolitan species with decreasing mean particle size of the stream bed. The reduction in endemic species may have been attributed by the negative effects of sedimentation, the loss of riffle habitat, reduced egg and fry survivorship, and lowered prey densities through habitat destruction or increased drift (Waters, 1995).

Despite significantly greater EPT densities in the Kuywa River, the contribution of each taxa was not even. Ephemeroptera dominated all the sites while Plecoptera missing in some sites for both dry and wet seasons. Ecologically health sites could be distinguished from impacted one by assessing the composition of their EPT. All the nine sites in Kuywa River were impacted especially by livestock resulting the absence of Plecoptera in all sites at least one of the seasons. Sites A, KG, KS and E could be the most impacted sites. Site A could be stressed from the agricultural chemicals used in the sugar cane plantation which find their way to the river through the runoff. Site KG had the riparian land planted with exotic vegetation (eucalyptus) which may not provide desired food for the benthic macroinvertebrates. In the actual sense, food quality and leaf toughness affect macroinvertebrate colonization (Gracia, 2014). Although site KS and E had young indigenous vegetation planted, their upstream was extensively cultivated for horticultural crops (mainly tomatoes, onions and iris potatoes) where fertilizers and pesticides were being applied. This finding concurs with other studies (Masese et al., 2009; Raburu, 2003) in which low relative abundances of EPT were observed in degraded areas. However, the low numbers of Plecoptera taxa and other stations having none was also observed in Moiben River by Masese et al. (2009) and attributed to catchment degradation. In Lake Victoria Basin where Kuywa is has shown to have higher Plecoptera than what was observed.

Raburu (2003) undertaking a study in the Nyando River of Lake Victoria Basin reported a well-representation of Plecoptera taxa which indicate their probable occurrence in the Kuywa. Their low numbers (Plecoptera) in Kuywa could also be attributed to the substrate which was either sandy or silt from the farms which do not form a conducive habitat for Plecoptera distribution, diversity and abundance (Lemly, 1982). Nevertheless, some of the tropical streams lack Plecoptera, as observed by Durand and Leveque (1981), cited in Masese et al. (2009) who reported only one Plecoptera species in the whole of West Africa.

The order Tricoptera which was the second most abundant in the EPT group was found to be more during the wet season compared to dry season except for sites E and KM. Sites A and KG had no Tricoptera order at all during the dry season (Table 14). It was worth nothing that site KS had the highest individuals in Tricoptera during the wet season. The control site KM had nearly balanced Tricoptera individuals for both seasons. For Plecoptera order, K1 had the highest individuals during the wet season. Sites A, KS and E had no Plecoptera for both dry and wet seasons. Site T1 and T2 had Plecoptera during the dry season and none in the wet season. The potential for higher diversity and abundance of macroinvertebrate taxa during the wet season than the dry season cannot be ignored. For instance, as part of their life-history strategies, some tropical insects mature and emerge during the wet season (Jacobsen, Cressa, & Dudgeon, 2008; Mathooko, 2001). Moreover, water quality in some streams deteriorate during the dry season (Masese et al., 2009). This might have accounted for more EPTs during the wet season.

Tricoptera individuals observed at site A and KG during the wet season and none in the dry season were mainly from the samples collected in the month of May, 2016. According to farmer's calendar in Kuywa catchment, the month of May all farms are covered by maize intercropped with beans. Since this month also the weeding has ended, less sediments are produced from the farms and less fertilizers are reaching the river. The crop cover might have favoured the flourishing of Tricoptera. Equally, quite a number of section of the Kuywa River, farmers cultivate up to the banks. This means when maize crop is high enough it forms the riparian zone vegetation required by macroinvertebrates. On contrary, during the month of January, the catchment is bare and ploughed in readiness for planting when the rains start. The farmers who have not protected their riparian vegetation cultivate to the banks thus rendering the river open canopy which discourage the survival of Tricoptera. The month of August the field are bare from beans and the maize already dried for harvesting and others already harvested thus not supporting Tricoptera life. Tricopterians are sensitive to disturbances and decrease with an increase in nutrient levels (Mason, 2002). The relative abundance of Tricoptera in the nine sampling sites was believed to be influenced by organic matter and availability of food for consumption. Organic matter may have included the leaf litter and falling stems from the riparian. This concurs with Aura et al. (2010) and Mason (2002), who found such results and attributed it to the influence of organic matter and food availability on the abundance and distribution of aquatic macroinvertebrates.

Ephemeroptera as was the case of Tricoptera might have flourished during the wet season due to the availability of organic matter and food. However, Ephemeroptera taxa has individuals which are more tolerant to pollution compared to the Tricoptera. Studies carried out by Masese et al. (2009) in Moiben River established less number of EPT individuals in the dry months (February and March) and more as the rain starts in the months of April and May due to succession. During the dry season especially in January when the sampling was carried out was the peak of the dry season, when conditions might have worsened in-stream as discharge declined, fine sediments settling down, temperature raising and dissolved oxygen becoming a limiting factor for the macroinvertebrates.

The temporal EPT species abundance described in the previous section was complimented with species richness to establish how many species of Ephemeroptera, Plecoptera and Tricoptera

(EPT) existed at different seasons of the year. Table 15 provides the results of EPT richness during the dry and wet seasons of 2016 at the nine sampling sites of Kuywa River.

Table 15: EPT species richness index for the nine Kuywa River sites sampled in dry and wet seasons

	Dry			**Wet**		
	Ephemeroptera (E)	**Plecoptera (P)**	**Tricoptera (T)**	**Ephemeroptera (E)**	**Plecoptera (P)**	**Tricoptera (T)**
A	3	0	0	4	0	2
KG	5	0	0	6	1	4
KS	3	0	1	5	0	4
K1	4	0	1	5	1	4
K2	5	0	2	6	0	4
T1	5	1	1	6	0	4
E	5	0	1	7	0	2
T2	6	1	7	5	0	4
KM	5	0	2	5	1	2
Mean	**4.6**	**0.2**	**1.7**	**5.4**	**0.3**	**3.3**

A- Alumuli at Ngueno, **KG-** Kibingei at Daraja Mbili, **KS-** Kibisi at Matisi, **K1-** Kuywa at Kuywa market, **K2-** Kuywa at Nakoyonjo, **T1-** Teremi at Kimorong falls, **E-** Emia at confluence with Teremi, **T2-** Teremi at confluence with Emia, **KM-** Kimurio at Chepyuk

EPT species richness ranged between 0 and 7 for both dry and wet seasons (Table 15). As in the case of the species abundance, there was a general trend of having more EPT species during the wet season than dry season. During the dry season, Ephemeroptera were found to be highest species richness index at site T2 (6) and lowest at site A (3). The wet season exhibited the highest species richness index of Ephemeroptera being at E (7) and lowest at A (4).The control site KM had the richness index of 5 for Ephemeroptera order during both dry and wet seasons. On average, the EPT richness in wet season was higher ranging between 0.3 and 5.4 (5.4, 0.3 and 3.3 respectively) while dry lied between 0.2 and 4.6 (4.6, 0.2 and 1.7 respectively).

The scores for species richness for the EPT in Kuywa River seemed to be low, and more especially for Tricoptera during the dry season and Plecoptera for both dry and wet seasons. Although Ephemeroptera are also highly sensitive to any change in ecosystem (lonowska-

Olejnik & Skalski, 2014), they were more rich in both seasons compared to Plecoptera and Tricoptera. Families in the order Plecoptera are mostly temperate-water invertebrates and very few species are known to exist in tropical waters (de Moor, Day, & de Moor, 2003; Masese et al., 2009; Orwa et al., 2013). The higher species richness for Ephemeroptera could be attributed by their tendency to live in both streams and still waters thus having a wider niche. Ephemeroptera are most common in cool, clear and shallow water (Bunn et al., 2010). Site T2 and KM which had high species richness during the dry season were the same sites with lowest temperatures at that season (16^{o}C and 13^{o}C, respectively). Sites E, T1, K2 and KG had also lower temperature compared with the other sites during the wet season. Low temperature has been found to favour high oxygen concentration. On turbidity, site T2 and KM were the lowest in the dry season, thus providing clear water for Ephemeroptera. Turbidity that is reported in Nephelometric Turbidity Units (NTU) serves as a measurement of numerous factors affecting water clarity. These factors include organic and inorganic particulate and suspended matter and dissolved substances that contribute to the colour of water. The finding of this study is similar to the ones of Hollinger, Cornish, Baginska, Mann, and Kuczera (2001), Costanza, Fisher, Mulder, Liu, and Christopher (2007), and Harding, Young, Hayes, Shearer, and Stark (1999) who have documented the contribution of turbidity to EPT ecosystems by agricultural practices. The less clear distinction of the control site KM from the rest is due to invasion of livestock upstream of the site. Other studies (Muenz, Golladay, Vellidis, & Smith, 2006; Vidon, Campbell, & Gray, 2008) have shown that livestock production impact water quality through increased turbidity and total suspended sediment concentration, particularly when livestock have unrestricted access to streams. In a study conducted by Vidon et al. (2008) streams allowing cattle access exhibited a 13-fold increase in turbidity when compared to protected sites.

In comparing the species abundance in Kuywa River, generally there were less presence of EPT individuals compared to other species. The EPT abundance as percentages of total collected benthic macroinvertebrates for dry and wet seasons are given in Table 16.

Table 16: EPT abundance as a percentage of total sampled macroinvertebrate at the nine sites of Kuywa River during the dry and wet seasons of 2016

Sampling site	**A**	**KG**	**KS**	**K1**	**K2**	**T1**	**E**	**T2**	**KM**
% EPT dry	1.0	3.3	3.4	4.5	14.6	7.2	5.5	7.1	3.8
% EPT wet	1.5	2.8	4.2	2.0	2.0	3.6	3.3	4.4	5.2

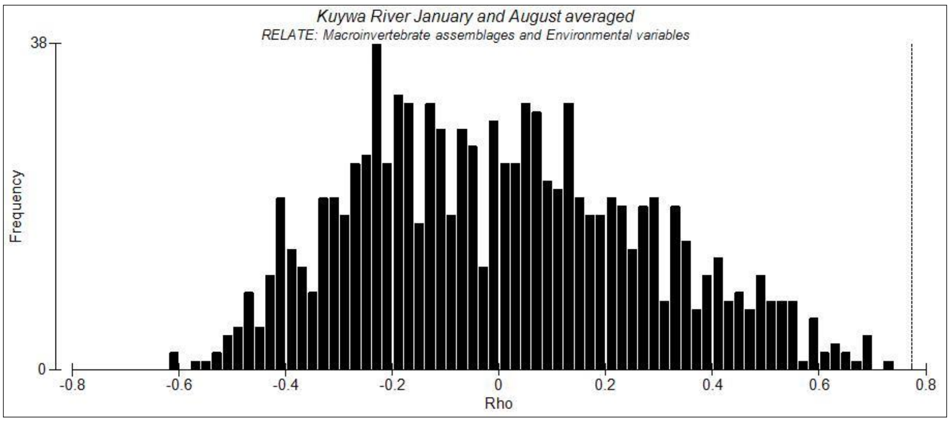
A- Alumuli at Ngueno, **KG-** Kibingei at Daraja Mbili, **KS-** Kibisi at Matisi, **K1-** Kuywa at Kuywa market, **K2-** Kuywa at Nakoyonjo, **T1-** Teremi at Kimorong falls, **E-** Emia at confluence with Teremi, **T2-** Teremi at confluence with Emia, **KM-** Kimurio at Chepyuk

The results in Table 16 shows that the percentage of EPT abundance to the total sampled benthic macroinvertebrates ranged between 1 and 14.6 for dry season (K2 being the highest) and 1.5 to 5.2 for the wet season (KM being the highest). This has an implication that some sites had a good water quality while others were poor. Only K2 had fairly good water quality during the dry season. In the wet season all sites had poor water quality. Sites A and KG had persistently poor water quality both in dry and wet seasons. NCDEHNR (1997) classifies sites with percent EPT of less than 15 but greater than 10.1 as good, 4.1 to 10.0 as fair and less than 4.0 as poor. This implied that six out of nine sites were poor in water quality during the wet season. This result is consistent with Hepp (2010) who established at Guilford creek in Guilford that low EPT representation in the river is attributed to point and non-point sources of pollution more prominent when there is low stream flows.

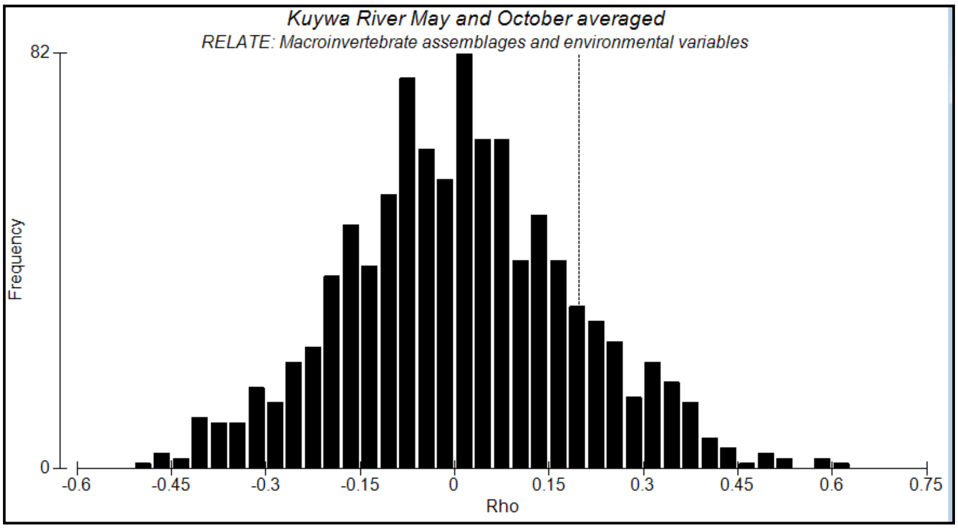
Kuywa River showed a 'Fair' water quality rating during the dry season and more 'Poor' during the wet season. For the dry season, the site with a 'Good' quality (K2) had good riparian vegetation cover for a stretch of about 200m upstream and 500m downstream. Hering et al.

(2015) report that majority of the long restored sections of riparian vegetation could cause a significant influence on the water quality. Their study further suggest the restored section to exceed 2km continuous so as to support populations of sensitive species. The condition of the riparian and upstream catchment practices impacts on in-stream substrate directly which affect the aquatic macrophytes and benthic macroinvertebrates (Hering et al., 2015). During the wet season the control site KM together with KS and T2 were rated 'Fair' compared to the rest which could be attributed by high discharge from the upper catchment which is in pristine condition. The findings are similar to those of Aura et al. (2010) who established that headwaters stations at Kipkaren River were dominated by taxa associated with unpolluted waters.

To test how closely related water quality parameters and benthic macroinvertebrate species abundance were in dry and wet seasons in the Kuywa River, RELATE routine of multivariate in Primer v6 was used. The null hypothesis was that water quality parameters were not related at all with benthic macroinvertebrate abundance in both dry and wet seasons in Kuywa River in 2016. Figure 14A-B presents the frequency histogram with which the true values of ρ can be compared with for dry and wet season.



(A)



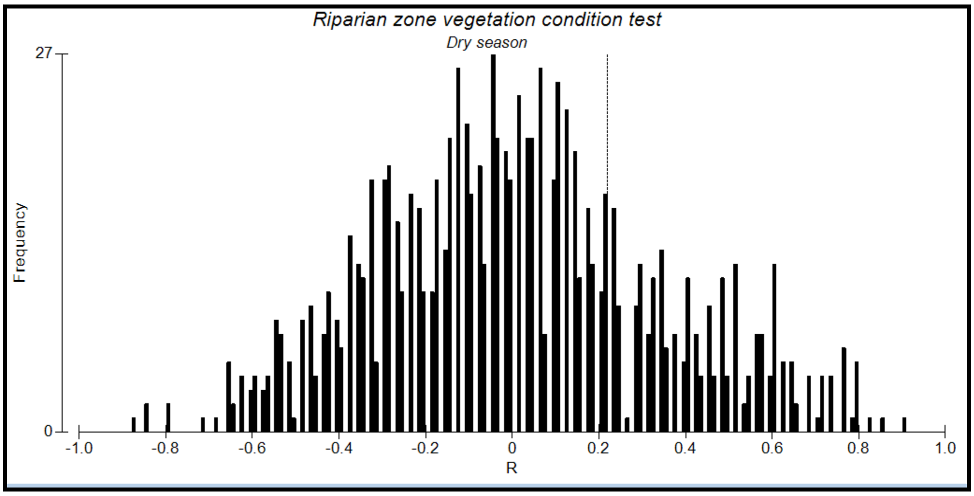
(B)

Figure 13A-B: RELATE frequency matrix for water quality parameters and benthic macroinvertebrate abundance with the true values of ρ. (A) Dry season with Rho=0.791, Sig=0.001; (B) Wet season with Rho=0.197, Sig=0.154

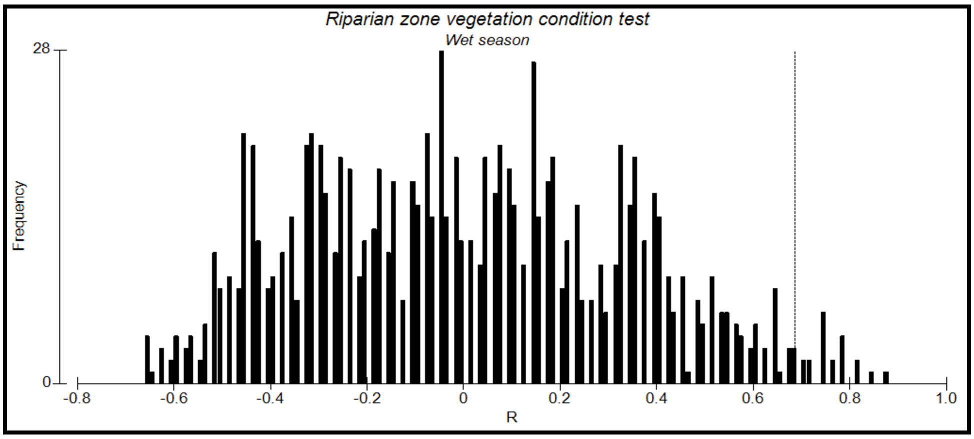
The result of hypothesis testing that water quality parameters were not related at all with benthic macroinvertebrate abundance in both dry and wet seasons in Kuywa River in 2016 indicated that during the dry season, Rho=0.791 ($p<0.001$) (Figure 13(A)). Since the distribution of ρ values are less than the true value, then the null hypothesis is rejected. On the other hand accepted during the wet season, Rho=0.197 ($p>0.1$) (Figure 13(B)). The indication is that the null hypothesis is accepted for the wet season. This implies that macroinvertebrate assemblages at different sites in Kuywa River are related to the water quality parameters for different sites mostly during the dry season.

RELATE routine led to the rejection of the null hypothesis (Rho=0.791, p=0.001) and therefore upheld the alternative that there was an agreement in water quality parameters and benthic macroinvertebrate assemblages in the Kuywa River during the dry season. On contrary, during the wet season the null hypothesis was accepted (Rho=0.197, p=0.154). The less response of macroinvertebrates to changes in water quality parameters during the wet season could be explained by the dilution effect of high discharge during the rains.

To test the null hypothesis that there were no differences in water quality parameters among the nine sampling sites of the Kuywa River during dry and wet seasons in 2016, ANOSIM test in Primer v6 was employed. The frequency distribution for hypothesis testing for both dry and wet seasons are given it Figure 14. R-values are a measures of variation between samples (sites) compared to variation within samples in similarities of a group of variables using ranked similarities among replicates (Clarke, Somerfield, & Gorley, 2008). The values close to zero represents the null hypothesis.



(A)



(B)

Figure 14A-B: Histograms of the permutation distribution of the ANOSIM test statistic, R, under the null hypothesis that there were no differences in water quality parameters among the nine sampling sites of the Kuywa River during dry and wet seasons. The frequency is centered on zero - if there are no difference in water quality parameters then the average rank resemblance among groups will be much the same, and R will be near to zero. The grey line is the true value of R which is 0.219 for dry and 0.688 for wet seasons.

The result in Figure 14 shows a grey line on histograms indicating R=0.219 (p=0.252) for dry season and R=0.688 (p=0.024) for wet season. The R value for the wet season was found to be much larger than most of the 999 permuted values, so the null hypothesis that there were no differences in water quality parameters among the nine sampling sites of the Kuywa River during dry and wet seasons was rejected at significance level of p<0.01. However, the null hypothesis was accepted for the dry season since the R value was almost the same as most of the 999 permuted values. Therefore, during the dry season the nine sites with different riparian conditions are the same (R=0.219, p=0.252) in terms of water quality parameters. This could be attributed by the minimal nutrients reaching the stream, especially since the riparian vegetation has been improved in some parts. This could also be explained from the PC1 (Figure 13) for the dry season which indicated that the sites were more loaded with physical variables more than chemical variables. In contrast, ANOSIM for wet season gave a conclusion that nine sites were different in terms of water quality parameters (R=0.688, p=0.02). It was the riparian vegetation and the upstream land use which may have differentiated the nine sites during the wet season. Riparian vegetation filters the materials from the ridge before the runoff gets into the river. However, due to short resident time of the runoff within the riparian zone, still quite some quantities get into the stream water. It should be noted that the patchy riparian vegetation planted along the Kuywa River may not work well to prevent much of the nutrients and sediments from the field. Those sites with dense, indigenous, continuous vegetation may have benefited from the likely foreign materials reaching the river system, thus receiving less nutrients and sediment as indicated in the results obtained during the wet season. This was consistent with the findings of Walsh et al. (2005) that streams are usually degraded due to the absence of the filtering mechanism provided by riparian zone vegetation.

To explore the 'best' combination of water quality parameters which explained the benthic macroinvertebrate assemblages in nine sampling sites of Kuywa River during the dry and wet season of 2016, BEST procedure in Primer v6 produced results in Table 17 (dry season) and Table 18 (wet season).

Table 17: Number of water quality parameters, spearman rank correlation and best water quality parameters selected to explain benthic macroinvertebrates assemblage during the dry season of 2016. Combination of the 7 water quality parameters, taken k at a time, yielding the best matches of macroinvertebrate and water quality parameters similarity matrices for each k as measured by weighted Spearman rank correlation ρ. Bold type indicates overall optimum.

Number of Variables(*k*)	Spearman Correlation(ρ)	Selections
3	0.499	3,4,5
4	**0.52**	3,4,5,7
4	0.5	2,3,5,7
5	0.512	1,3,4,6,8
5	0.507	1,3,4,5,6
5	0.507	1,3,4,5,7
5	0.5	2,3,4,5,7
6	0.514	1,2,3,4,5,6
6	0.495	1,3,4,6,7,8
7	0.515	1,2,3,4,5,6,7

1=pH, 2=Log (TDS), 3=DO, 4=Log (PO_4), 5=Log (NO_2), 6=Log (NO_3), 7=Log (TN), and 8=Log (Q)

Table 18: Number of water quality parameters, spearman rank correlation and best water quality parameters selected to explain benthic macroinvertebrate assemblages during the wet season in 2016. Bold type indicates overall optimum.

Number of Variables(*k*)	Spearman Correlation(ρ)	Selections
1	**0.421**	8
4	0.4	1,4,6,10
4	0.397	1,3,8,10
4	0.399	1,3,6,10
5	0.402	1,3,7,8,10
6	0.394	1-3,5,8,10
6	0.411	1-3,7,8,10
6	0.4	1,2,4,7,8,10
7	0.399	1-3,7,8,9,10
7	0.395	1,2,4,7,8,9,10

1=T, 2=pH, 3=Log (EC), 4=Log (TDS), 5=Log (TSS), 6=Log (SO_4), 7=Log (PO_4), 8=Log (TP), 9=Log (Q) and 10=Log (CC)

The result of Table 17 shows that there was no single physico-chemical variable which best groups the nine sites of the Kuywa River in the dry season in a manner consistent which benthic macroinvertebrate assemblage patterns (Table 17). The best 3-variable combination (DO, Log

(PO_4) and Log (NO_2)) (ρ=0.499) provided the least number of water quality parameters to group the nine sites during the dry season (Table 17). However, it is the 4-variable combination which involve the same variable DO, Log(PO_4) and Log(NO_2) but adding Log(TN) which best grouped the nine sites (ρ=0.52) during the wet season in a accordance with the macroinvertebrate assemblage patterns. The best 5, 6 and 7-variable combinations retained DO and Log (PO_4) but ρ-values start dropping. The dominant variables for best combinations during the dry season were DO, Log (PO_4) and Log NO_2) (Table 17). The dilution influence was also evident in the BEST procedure in the Primer v6. The dry and wet seasons had different 'best' match between the multivariate among-sample patterns of Kuywa River assemblages and that from water quality parameters associated within them. In the wet season a single variable (Total phosphorus) had the highest correlation (ρ=0.421). The rest of the water quality parameters may have reduced their influence and correlation due to the dilution influence of high discharge in the river. Phosphorus may have been contributed from the small scale agricultural farms which use fertilizers for both planting and top dressing of the crops during the wet season. This finding is consistent with Brett et al. (2005) and Wallace et al. (2013) who noted that the change in stream discharge has an influence t of reducing the water quality in streams.

During the wet season as provided in Table 18, combinations were quite different. The single physico-chemical variable which best groups the nine sites of Kuywa River in the wet season, in a manner consistent with benthic macroinvertebrate assemblages is Log(TP) (ρ=0.421) (Table 18). This single variable generates the best result for grouping the nine sites. In wet season there are no 2-variable nor 3-variable combinations which best groups the nine sites. The best variable combinations were dominated by Temperature, Long (TP) and Log (CC).

The dry season macroinvertebrates were 'best' explained by dissolved oxygen, Log (phosphate), Log (nitrite) and Log (total nitrogen) due to low flows in the stream which makes these nutrients have a higher concentration. Studies by Mason (2002) and Masese et al. (2009) indicate that EPT group of macroinvertebrates are sensitive to nutrients which make them reduce during the dry season. This may have been the reason for high correlation since the river had high percentage of individuals in this group. During the dry season, increased temperature, nutrient concentration and light intensity increased in-stream primary production which favour more macroinvertebrates. The increase in macroinvertebrates may have increased the demand for oxygen making it the limiting factor. However due to the river morphology, there may have been a lot of oxygenation going on but controlled by temperature and canopy cover as given in the next 'best' combination.

In summary, both water quality parameters and benthic macroinvertebrate assemblages showed temporal variations among different seasons of the year in Kuywa River. Five sites (A, KG, KS, K1 and K2) had higher pH values during the wet season compared to those of dry season. Electrical conductivity indicated mixed trend among the sites, KS, K1, K2 and E having higher values in dry season. The study established that all the nine study sampling sites had higher values of turbidity during the dry season as compared to the wet season. For total suspended solids, the sites located at the lower parts of the river such as A, KG, KS, K1 and E had higher values during the dry season (32mg/l, 193mg/l, 129mg/l, 114mg/l and 109mg/l respectively). For chemical variables, wet season had higher values in five sites (KS, K1, K2, T1 and KM). All sites except site A and site KM, had higher values of orthophosphate during the wet season. It was clear in both dry and wet seasons nitrites (NO_2) and nitrates (NO_3) increased downstream of Kuywa River. Six sites (A, K2, T1, E, T2 and KM) out of nine sites had higher values of total phosphorus (TP) in wet season than was in the dry season. In exploring the variance-covariance structure of water quality parameters in the nine Kuywa River sites, PC1 and PC2 explained a total of 68.3% for dry season and 68% for the wet season which was more or less the same. For temporal patterns in benthic macroinvertebrates, a total of 2,330 and 5,112 individuals were collected for dry and wet seasons respectively. Dry season was dominated by *Baetis sp.* (34%) while wet season was dominated by *Simulium sp.* (51%). All sites except site A showed higher species richness in dry season. Five sites (A, KG, KS, K1 and KM) out of nine showed higher species evenness during the dry season than in the wet season. Shannon-Wiener Index was higher in the wet season for six sites (KG, KS, K2, T1, T2 and E) out of nine sampling sites. Temporal variability was also observed at sensitive orders Ephemeroptera, Plecoptera and Tricoptera (EPT). Ephemeroptera dominated EPT group in both seasons. Tricoptera were found to be more in the wet season compared to dry season. Control site KM had balanced Tricoptera for both seasons. During the study period EPT species richness ranged between 0 and 7 for both dry and wet seasons. EPT species richness was higher during the wet season. Benthic macroinvertebrates in Plecoptera order were found to be very rare in Kuywa River in both seasons. EPT as a percentage of all benthic macroinvertebrate collected was very low ranging between 1%-14.6% for dry season and 1.5%-5.2% for the wet season. The null hypothesis that water quality parameters were no related at all with benthic macroinvertebrate abundance in both dry and wet seasons in the Kuywa River in 2016 was rejected for dry season at Rho=0.791 ($p<0.001$) and accepted for wet season ($p>0.1$) using RELATE procedure. On the other hand, the null hypothesis that there were no differences in water quality parameters among the nine sites of Kuywa River during the dry and wet seasons in 2016 was rejected for wet season (R=0.688, p=0.024) and accepted for dry season ($p>0.1$) using ANOSIM routine in Primer v6. The BEST procedure to explore best match of water quality parameters which influenced benthic macroinvertebrate assemblages in Kuywa River at nine sampling sites indicated log TP to have the highest influence ($\rho=0.421$) during the wet season. However, in dry season a combination of four variables (DO, $LogPO_4$, $LogNO_2$ and TN) provided the best number of water quality parameters ($\rho=0.52$) to group the sites during the dry season.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter brings out a summary of the study findings, conclusions, and recommendations. Further it provides a suggestion of areas for further research in order to exploit more into the studied topic.

5.2 Summary of the findings

The study established that in Kuywa River altitude ranged 1440m to 2304m a.s.l., depth between 0.15m to 0.61m, stream width 1.8m to 7.02m., and discharge 0.11m3/s to 3.09m3/s. All nine sites were well oxygenated ranging between 6.9 mg/l to 8.4 mg/l. Study indicated that nutrients in Kuywa River increased in concentration downstream site A having 1.6 mg/l while KM had 0.9 mg/l of TN. All study sites has total nitrates higher than 0.07 mg/l which was for the control site KM. Spearman rank correlation indicated some that some water quality parameters were related to benthic macroinvertebrate species abundance while others did not respond. *Elassoneuria sp.* (r=0.83), *Ephemerella sp.* (r=0.82) and *Macrobdella* sp. (r=0.87) were highly positive correlated with phosphorus. *Elassoneuria* sp. (r=0.85), *Ephemerella sp.* (r=0.78) and *Macrobdella sp.* (r=0.85) were highly positive correlated with pH. *Elassoneuria* sp. (r=0.78), *Ephemerella sp.* (r=0.79), *Macrobdella sp.* (r=0.90) and *Actnonaias* sp. (r=0.91) were highly positive correlated to DO. However, *Astacus sp.* (r=-0.78) and *Tubifex sp.* (r=-0.84) were highly negative correlated to sulphates, and Leptophlebiidae (r=-0.766), *Ephemerella sp.* (r=-0.76) and *Limonia sp.* (r=-0.63) were negatively correlated to TP. These findings led to the rejection of the null hypothesis that water quality variables (e.g. turbidity, pH, total nitrogen) had no relationship with benthic macroinvertebrate species abundance in the Kuywa River. Spearman rank correlation between water quality parameters and benthic macroinvertebrate species diversity and richness indices indicated that only TDS ($r=0.6$, $\rho=0.04$) and PO4 ($r=0.78$, $\rho=0.01$) were statistically significant with Margalef richness index. Other indices were not significant. Thus the null hypothesis that water quality parameters (e.g. turbidity, pH, total nitrogen) had no relationship with benthic macroinvertebrate species diversity in the Kuywa River was rejected.

The study established that, two sampling sites (KM and K2) had ‘Excellent’ riparian vegetation cover, four (A, KS, T2 and E) ‘Good’ and two (KG and T1) ‘Poor’. Spearman rank correlation between riparian vegetation cover and benthic macroinvertebrate abundance established that, *Hexatoma sp.*, *Belostoria sp.* and *Simulium sp.* were significant positively correlated ($r=0.83$, $r=0.73$ and $r=0.62$ respectively $p<0.05$). On the other hand, *Anacalis sp*. and Notonectidae were significant negatively correlated ($r= -0.63$, $r= -0.69$ respectively, $p<0.05$) to riparian vegetation cover. The study established that site K2 and T2 had the highest (35) species richness while site A situated in sugarcane plantation had the lowest (26). Site E recorded the highest species diversity (2.55) while K1 had the lowest (0.89). The null hypothesis that there were no species abundance differences between sites with ‘Excellent’ ‘Good’ and ‘Poor’ riparian vegetation cover was rejected at Global $R=0.94$ ($p<0.1$) using ANOSIM procedure. The role of individual species in contributing to the dissimilarity of sites with different riparian vegetation cover indicated that the greatest contributor was *Simulium sp.* (12.85%), *Gompus sp.* (4.29%) and *Baetis sp.* (4.15%) for ‘Excellent’ and ‘Poor’ sites. The sites with ‘Good’ and ‘Poor’ the contributors were *Simulium sp.* (9%), *Baetis sp.* (6.79%), and *Elassoneuria sp*. (4.18%). Multidimensional Scaling (MDS) plots for *Megalagrion sp*. and *Simulium sp.* indicated that sites with mature planted and natural conserved riparian vegetation cover favoured most benthic macroinvertebrates. The null hypothesis that benthic macroinvertebrate abundance did not differ among the nine sampling sites of Kuywa River was rejected (Pi=3.215, $p<0.001$) through SIMPROOF procedure. For the sensitive species, 36% of individuals belonged to the EPT group of species. Site K2 which had 'Excellent' riparian vegetation cover had the highest number of EPT individuals (16.5%) while the control site KM had 13.2%. The study established that in Kuywa River there were more Ephemeroptera abundance followed by Tricoptera while Plecoptera were negligible in number. Equally, Ephemeroptera had the highest species richness and diversity compared to Tricoptera and Plecoptera.

The study established that water quality parameters differed significantly between wet and dry seasons. Site T1 and K2 had higher temperatures in wet season (16.6ºC, 19.2ºC respectively) compared to dry season (15.1ºC, 18.7ºC respectively), while the rest of the sites were more cold in wet season than in dry season. It was also established that nitrites and ortho phosphate concentrations were higher during the wet season compared to the dry season. Other nutrients which were higher during the wet season than dry included nitrates, phosphorus and total nitrogen. The study established that EPT reduced in abundance during the dry season and replaced by tolerant species such as *Chironomous sp., Hydropsyche sp., Gompus sp.,* and Oligochaeta. During the wet season, Ephemeroptera species richness were higher at site T2 (6) and lowest at site A (3) while in the dry season highest was E (7) and lowest still A (4). Tricoptera richness during the wet season was nearly the same (4) for all sites except site E and KM which had 2, while in dry season richness declined for all sites to index of less than 2. Plecoptera were rare in both seasons. The null hypothesis that water quality parameters were no related at all with benthic macroinvertebrate abundance in both dry and wet seasons in the Kuywa River in 2016 was rejected for dry season at Rho=0.791 ($p<0.001$) and accepted for wet season ($p>0.1$) using RELATE procedure. On the other hand, the null hypothesis that there were no differences in water quality parameters among the nine sites of Kuywa River during the dry and wet seasons in 2016 was rejected for wet season ($R=0.688$, $p=0.024$) and accepted for dry season ($p>0.1$) using ANOSIM routine in Primer v6. The BEST procedure to explore best match of water quality parameters which influenced benthic macroinvertebrate assemblages in Kuywa River at nine sampling sites indicated log TP to have the highest influence ($\rho=0.421$) during the wet season. However, in dry season a combination of four variables (DO, LogPO_4, LogNO_2 and TN) provided the best number of water quality parameters ($\rho=0.52$) to group the sites during the dry season.

5.3 Conclusions

The study established that water quality parameters in the Kuywa River had both negative and positive relationship with some species of macroinvertebrates at different sites. The sensitive species of macroinvertebrates were positively correlated with physical variables such as oxygen and higher PH values while negatively correlated to nutrients, and other physical chemical variables such as turbidity, TDS and TSS. This implied that those sections with unfavourable physical chemical conditions will lead to extinction/reduction of sensitive macroinvertebrate species. This extinction will have an impact on chemical processes which these organisms play and their importance in the food web. On the other hand tolerant species were found to be positively correlated with nutrients, temperature, TSS, and TDS. Increased tolerant species signified deteriorated river health and imbalanced macro fauna assemblage in the river system.

The riparian vegetation cover mimicking natural conserved riparian vegetation cover favoured diverse sensitive and non-sensitive benthic macroinvertebrate species. The riparian vegetation which brings about larger substrate changes are required for the balanced species diversity and evenness, as revealed by the differences in Bray–Curtis similarities between sites with woody debris from riparian and those with open riparian. Influence of riparian vegetation cover restoration measures on aquatic biota strongly depend on the capacity of the vegetation to establish diverse habitat including its percentage land cover to control material movement from the ridge. Sections of Kuywa River with poor canopy cover increased in-stream light intensity thus lowering oxygen concentration due increased temperature. The establishment of riparian zone vegetation with dense canopy cover appears to be important in controlling the in-stream temperature and providing allochthonous materials for benthic macroinvertebrates. Lower temperature increases the capacity of stream water to hold more dissolved oxygen needed for aquatic fauna. Further, allochthonous materials provide food for aquatic fauna. Lower oxygen concentration may lead to reduction of sensitive species from the river system thus impacting on the functioning of aquatic ecosystem.

Kuywa River experienced temporal variability in water quality parameters which also led to temporal variability in benthic macroinvertebrate assemblages. The concentration for both total phosphate and total nitrogen remained high (>0.2mg/l) suggesting that there was high influence of anthropogenic interference in agricultural streams. The wet season had higher concentrations of nutrients compared to dry season. Kuywa River was healthier in dry season compared to wet season which led to more diverse of macroinvertebrate assemblages in the dry season. Therefore, seasonality was a factor that influenced the physical and chemical characteristics of streams and benthic macroinvertebrate assemblages. The continual degradation of the catchment without establishing/maintaining a riparian buffer zone along the river Kuywa will deteriorate the health of the Kuywa River more in future

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5.4 Recommendations

Based on the findings and conclusions of the study, the recommendation below are given to maintain the health of Kuywa River.

i. Planting of riparian vegetation to improve the river health should encourage the use of those plants which could reduce the materials from adjacent land reaching the stream water. Those trees which encourage undergrowth will reduce nutrients and other materials which contaminate the stream water.
ii. There should be a continuous riparian vegetation cover when rehabilitating the river systems. This was evidenced from the study at site K1 which has excellent riparian vegetation did not do well in benthic macroinvertebrate assemblages, as these macroinvertebrates need corridors for dispersal. Planting of riparian vegetation to begin from the headwaters down through the catchment and a continuous buffer length be achieved. This would ensure that all contaminants from the farms including plantations will be filtered before runoff ends in the stream.
iii. Basing on generalizations on the findings of this study, the researcher recommends that riparian vegetation cover should be increased along the Kuywa River in order to moderate temperatures more especially during the dry season, provide CPOM for instream biota, and control movement of contaminants into the stream. This action would boost benthic macroinvertebrate species evenness and abundance in the Kuywa River.

5.5 Areas for further research

i. The present study concentrated on the main Kuywa River. This study recommend for study to be undertaken at the tributaries to establish how much influence they exert on the main trunk in terms of water quality parameters.

ii. This study highlighted the importance riparian zones on protecting the health of the Kuywa River. Although there was an indication that even a 10-m strip (distance) makes a difference for stream ecosystems, additional research is needed to establish minimum riparian buffers to protect stream health.

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APPENDIX 1: BENTHIC MACROINVERTEBRATE SPECIES ABUNDANCE IN THE NINE SAMPLING SITES OF KUYWA RIVER DURING THE STUDY PERIOD JANUARY TO OCTOBER, 2016

Site/Species	**A**	**KG**	**KS**	**K1**	**K2**	**T1**	**E**	**T2**	**KM**	**TOTAL**
Gomphus	14	9	32	3	26	62	43	49	13	**251**
Paragomphus	0	2	0	0	0	0	0	0	0	**2**
Zygopteran	0	3	0	0	0	0	0	0	0	**3**
Megalagrion	6	0	6	20	14	7	13	4	14	**84**
Diplacode	0	0	1	0	0	1	0	0	0	**2**
Orthetrum	0	0	0	0	0	1	0	0	0	**1**
Aeshnidae	1	1	0	2	2	0	0	3	5	**14**
Crocothemis	0	0	0	0	1	0	0	0	0	**1**
Lestes	9	9	56	15	34	33	19	20	16	**211**
Baetis	77	132	134	143	320	226	159	152	232	**1575**
Acanthiops	1	0	0	0	0	0	0	0	0	**1**
Caenis	6	5	10	4	6	10	8	4	2	**55**
Leptohyphidae	0	1	0	0	0	0	0	0	0	**1**
Afronurus	1	19	44	1	2	7	19	7	29	**129**
Euthraulus	5	3	0	1	0	0	1	0	0	**10**
Hydrovatus	1	0	1	0	0	0	0	0	0	**2**
Gerries	3	4	0	0	0	0	0	0	0	**7**
Belostoma	4	0	0	1	3	1	0	1	0	**10**
Polypotomus	1	1	1	3	0	0	0	1	0	**7**
Goerodes	0	0	4	0	0	2	0	0	0	**6**
Lepidostoma	0	5	11	2	26	19	9	19	0	**91**
Chimera	1	3	0	2	3	0	0	0	3	**12**
Ecnomus	0	0	2	0	0	1	0	0	0	**3**
Leptocerus	0	0	0	0	0	0	0	1	0	**1**
Astacus	2	0	0	0	0	0	2	1	0	**5**
Potamonaute	2	3	0	2	0	0	0	3	4	**14**
Cyrinus	0	1	0	1	7	0	2	1	0	**12**
Potamodyte	1	6	4	7	8	3	6	3	18	**56**
Elmnae	0	0	1	0	7	0	0	3	5	**16**
Proteneura	0	0	0	1	0	0	0	2	0	**3**
Chrysomelidae	0	0	0	0	3	0	0	0	0	**3**
Chironomous	153	24	43	48	53	23	97	20	52	**513**
Tanypodinae	11	3	8	6	16	4	8	0	4	**60**

Site/Species	A	KG	KS	K1	K2	T1	E	T2	KM	TOTAL
Orthocladiinae	0	0	1	0	0	0	0	0	0	**1**
Hexatoma	0	2	0	0	0	1	1	1	0	**5**
Belostoria	0	0	1	1	0	0	0	0	0	**2**
glossiphoria	0	0	1	0	0	0	0	0	0	**1**
Haplogenis	1	12	21	15	11	18	7	24	16	**125**
Goerodes	0	0	0	0	0	0	1	0	0	**1**
Tricorythus	0	17	22	11	38	25	22	13	14	**162**
Leptophlebiidae	0	10	0	1	3	0	6	14	21	**55**
Teleganodidae	0	0	0	0	2	0	0	0	0	**2**
Oligoneuridae	0	0	0	6	0	9	0	0	0	**15**
Elassoneuria	0	1	1	0	1	5	43	111	6	**168**
Polypotomus	0	0	0	2	0	0	0	0	0	**2**
Hydropsyche	7	9	44	12	26	29	21	28	28	**204**
Leptoceridae	0	2	5	1	5	1	0	4	1	**19**
Amphinenva	0	0	0	0	0	3	0	0	0	**3**
Ariacalis	0	0	0	0	0	2	0	2	0	**4**
Perlidae	0	1	0	4	0	0	0	0	1	**6**
Mesoperla	0	1	0	0	1	11	0	0	2	**15**
Simulium	4	1	0	0	0	45	0	6	0	**56**
Tricorythus	0	17	22	11	38	25	22	13	14	**162**
Leptophlebiidae	0	10	0	1	3	0	6	14	21	**55**
Teleganodidae	0	0	0	0	2	0	0	0	0	**2**
Oligoneuridae	0	0	0	6	0	9	0	0	0	**15**
Elassoneuria	0	1	1	0	1	5	43	111	6	**168**
Polypotomus	0	0	0	2	0	0	0	0	0	**2**
Hydropsyche	7	9	44	12	26	29	21	28	28	**204**
Leptoceridae	0	2	5	1	5	1	0	4	1	**19**
Amphinenva	0	0	0	0	0	3	0	0	0	**3**
Ariacalis	0	0	0	0	0	2	0	2	0	**4**
Perlidae	0	1	0	4	0	0	0	0	1	**6**
Mesoperla	0	1	0	0	1	11	0	0	2	**15**
Mesoperla	0	0	0	0	0	0	0	0	2	**2**

Site/Species	A	KG	KS	K1	K2	T1	E	T2	KM	TOTAL
Ephemerella	0	0	0	0	0	0	148	1	9	**158**
Simulium	381	14	30	1519	391	34	139	12	490	**3010**
Limnophora	0	0	0	0	1	0	1	0	0	**2**
Hexatoma	0	0	1	0	0	0	1	0	0	**2**
Limonia	1	1	1	0	1	0	1	0	2	**7**
Athericidae	0	0	0	0	1	0	0	0	0	**1**
leach	0	0	0	0	0	0	2	14	0	**16**
Nepus	0	0	0	0	0	0	2	1	0	**3**
Neridae	0	0	0	0	0	0	0	0	0	**0**
Naucoris	1	1	0	0	0	0	2	0	0	**4**
Corixine	0	0	0	0	0	0	1	0	0	**1**
Micronecta	3	0	0	0	1	0	1	0	0	**5**
Notonectidae	0	1	0	0	1	1	0	0	0	**3**
Pleidae	0	1	2	2	2	0	0	0	0	**7**
Tubifex	9	3	1	9	6	0	14	6	5	**53**
Lumbricus	1	0	1	10	3	0	4	5	0	**24**
Synclita	0	1	1	0	1	14	4	1	4	**26**
Macrobdella	0	0	1	3	0	4	7	5	49	**69**
Mesovelia	0	0	0	0	0	0	1	0	0	**1**
Actnonaias	0	0	3	0	0	5	29	1	5	**43**
TOTAL	**707**	**312**	**495**	**1858**	**1026**	**607**	**844**	**543**	**1052**	**7444**

A- Alumuli at Ngueno, **KG-** Kibingei at Daraja Mbili, **KS-** Kibisi at Matisi, **K1-** Kuywa at Kuywa market, **K2-** Kuywa at Nakoyonjo, **T1-** Teremi at Kimorong falls, **E-** Emia at confluence with Teremi, **T2-** Teremi at confluence with Emia, **KM-** Kimurio at Chepyuk

APPENDIX 2: EIGENVALUES AND EIGENVECTORS FOR PRINCIPAL COMPONENTS ANALYSIS (PCA) OF WATER QUALITY PARAMETERS FOR NINE SITES IN KUYWA RIVER DURING THE DRY PERIOD (JANUARY AND AUGUST) AND WET PERIOD (MAY AND OCTOBER), 2016.

a) Eigenvalues For dry season

PC	Eigenvalues	%Variation	Cumulative %Variation
1	5.6	40	40
2	3.96	28.3	68.3

b) Eigenvectors for the dry season

Variable	PC1	PC2
T	-0.286	0.34
pH	0.257	-0.304
Ec	-0.394	-0.141
TDS	-0.384	-0.151
DO	0.276	-0.265
Tb	-0.389	-0.108
TSS	-0.375	-0.167
PO4	-0.159	-0.232
NO2	-0.125	0.456
NO3	-0.112	0.158
TP	-0.326	-0.158
TN	-0.06	0.464
Q	-0.119	-0.316
CC	0.066	0.109

c) Eigenvalues for the wet season

PC	Eigenvalues	%Variation	Cumulative %Variation
1	6.18	41.2	41.2
2	4.02	26.8	68

d) Eigenvectors for the wet season

Variable	PC1	PC2
T	0.201	0.33
pH	-0.144	-0.013
EC	-0.021	0.46
TDS	-0.014	0.461
DO	-0.099	-0.328
Tb	-0.236	0.347
TSS	-0.363	0.173
SO4	-0.308	0.084
PO4	-0.278	0.296
NO2	0.337	0.234
NO3	0.358	0.049
TP	-0.304	-0.043
TN	0.347	0.181
Q	-0.337	-0.003
CC	0.035	-0.151

Temp - temperature, Ec - electro conductivity, TDS - total dissolved solids, DO - dissolved oxygen, Turb - turbidity, Sulp - sulphates, Phos - ortho phosphorous, NO2 - nitrites, NO3 - nitrates, TP - total phosphorus, TN - total nitrates and Q - discharge.

A- Alumuli at Ngueno, **KG-** Kibingei at Daraja Mbili, **KS-** Kibisi at Matisi, **K1-** Kuywa at Kuywa market, **K2-** Kuywa at Nakoyonjo, **T1**- Teremi at Kimorong falls, **E-** Emia at confluence with Teremi, **T2-** Teremi at confluence with Emia, **KM-** Kimurio at Chepyuk

APPENDIX 3: PHYSICAL CHARACTERIZATION/WATER QUALITY FIELD DATA SHEET

1. **STREAM NAME ____________________________________**
2. **LOCATION ____**
3. **LAT ______________________ LONG __________________**
4. **INVESTIGATOR _____________________________________**
5. **DATE ____**
6. **WEATHER CONDITIONS**

a) NOW

☐ Storm (heavy rain)

☐ Rain (Steady rain)

☐ Showers (Intermittent)

___% ☐ % Cloud Cover

☐ Clear/Sunny

b) Past 24 hours

i. Has there been heavy rain in the last 7 days? ☐ Yes ☐ No

ii. Air temperature _________________

iii. Others

____

____

7. **SITE LOCATION (Photo)**

8. **WATERSHED FEATURES**

a) Predominant surrounding land use

☐ Forest ☐ Field/pasture ☐ Agricultural

☐ Residential ☐ Commercial ☐ Industrial

☐ Others ____________________________________

b) Local watershed non-point source pollution

☐ No evidence ☐ some evidence ☐ obvious source

c) Local watershed erosion

☐ None ☐ moderate ☐ heavy

9. RIPARIAN VEGETATION COVER (30m buffer)

a) Estimated Riparian Length ___________________________m
b) Estimated Stream Width ______________________________m
c) Sampling Reach ____m
d) Area in ____m2
e) Estimated Stream Depth _______________________________m
f) Age of the trees _______________________________________yrs
g) Canopy cover ____
h) Vegetation type ______________________________________

☐ Partly open ☐ partly shaded ☐ shaded

i) Proportion of Reach represented by stream morphology types

☐ Riffle ______% ☐ Run _______% ☐ Pool _____%

10. LARGE WOODY DEBRIS (LWD)

a) LWD ________m2
b) Density of LWD _________m2/km2 (LWD/Reach Area)

11. AQUATIC VEGETATION

a) Dominant type and species present

☐ Rooted submergent

☐ Rooted floating ☐ Free floating

☐ Floating algae ☐ Attached algae

b) Dominant species present __________________________
c) Portion of the reach with aquatic vegetation __________%

12. WATER QUALITY PARAMETERS

a) Temperature ____________________________________0C
b) Specific conductance ______________________________
c) Dissolved Oxygen _________________________________
d) pH ____
e) Turbidity ____
f) Total Dissolved Solids ____________________________
g) TSS ____
h) BOD ____
i) Sulphate ____
j) Phosphate ____

k) Nitrate ____
l) Nitrite ____
m) TP ____
n) TN ____
o) WQ Instrument used _______________________________

13. ORGANIC SUBSTRATE COMPONENTS (May not necessarily add up to 100%)

Substrate Type	Characteristics	% Composition in the sampling area
Detritus	Sticks, wood, coarse plant materials	
Muck-mud	Black, very fine organic materials	
Marl	Grey, shell fragments	

14. BENTHIC MACROINVERTEBRATES

a. Order ____
b. Family ____
c. Species ____

APPENDIX 4; PROPOSAL APPROVAL

MASENO UNIVERSITY
SCHOOL OF GRADUATE STUDIES

Office of the Dean

Our Ref: PHD/NS/00008/2014

Private Bag, MASENO, KENYA
Tel:(057)351 22/351008/351011
FAX: 254-057-351153/351221
Email: sgs@maseno.ac.ke

Date: 14th April, 2016

TO WHOM IT MAY CONCERN

RE: PROPOSAL APPROVAL FOR JOASH ORUTA NYAKORA — PHD/NS/00008/2014

The above named is registered in the Doctor of Philosophy programme in the School of Environment & Earth Sciences, Maseno University. This is to confirm that his research proposal titled "Effect of Planted Riparian Buffer Vegetation in Protecting the Health of River by Analysing Benthic Macroinvertebrate Assemblages: A Case Study of Kuywa River, Bungoma County, Kenya" has been approved for conduct of research subject to obtaining all other permissions/clearances that may be required beforehand.

Prof. P.O. Owuor
DEAN, SCHOOL OF GRADUATE STUDIES

MASENO UNIVERSITY
DIRECTOR
15 APR 2016
SCHOOL OF GRADUATE STUDIES

Maseno University *ISO 9001:2008 Certified*

APPENDIX 5; RESEARCH AUTHORIZATION

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

Telephone:+254-20-2213471,
2241349,3310571,2219420
Fax:+254-20-318245,318249
Email:dg@nacosti.go.ke
Website: www.nacosti.go.ke
when replying please quote

9th Floor, Utalii House
Uhuru Highway
P.O. Box 30623-00100
NAIROBI-KENYA

Ref: No.
NACOSTI/P/16/14487/13090

Date:

17th August, 2016

Joash Oruta Nyakora
Maseno University
Private Bag
MASENO.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on **"*Effects of planted riparian buffer vegetation in protecting the health of a river by analysing benthic macroinvertebrate assemblages: A case study of the Kuywa River, Bungoma County, Kenya,*"** I am pleased to inform you that you have been authorized to undertake research in **Bungoma County** for the period ending **17th August, 2017.**

You are advised to report to **the County Commissioner and the County Director of Education, Bungoma County** before embarking on the research project.

On completion of the research, you are expected to submit **two hard copies and one soft copy in pdf** of the research report/thesis to our office.

BONIFACE WANYAMA
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Bungoma County.

The County Director of Education
Bungoma County.

APPENDIX 6; RESEARCH PERMIT

THIS IS TO CERTIFY THAT:
MR. JOASH ORUTA NYAKORA
of MASENO UNIVERSITY, 0-40100
KISUMU,has been permitted to conduct
research in *Bungoma County*

on the topic: *EFFECT OF PLANTED RIPARIAN BUFFER VEGETATION IN PROTECTING THE HEALTH OF A RIVER BY ANALYSING BENTHIC MACROINVERTEBRATE ASSEMBLAGES: A CASE STUDY OF THE KUYWA RIVER, BUNGOMA COUNTY, KENYA*

for the period ending:
17th August,2017

Permit No : NACOSTI/P/16/14487/13090
Date Of Issue : 17th August,2016
Fee Recieved :Ksh 2000

....
Applicant's Signature

....
Director General
National Commission for Science, Technology & Innovation

CONDITIONS

1. You must report to the County Commissioner and the County Education Officer of the area before embarking on your research. Failure to do that may lead to the cancellation of your permit.
2. Government Officer will not be interviewed without prior appointment.
3. No questionnaire will be used unless it has been approved.
4. Excavation, filming and collection of biological specimens are subject to further permission from the relevant Government Ministries.
5. You are required to submit at least two(2) hard copies and one (1) soft copy of your final report.
6. The Government of Kenya reserves the right to modify the conditions of this permit including its cancellation without notice

REPUBLIC OF KENYA

NACOSTI

National Commission for Science, Technology and Innovation

RESEACH CLEARANCE PERMIT

Serial No.A 10656

CONDITIONS: see back page

APPENDIX 7; ETHICS REVIEW COMMITTEE APPROVAL

MASENO UNIVERSITY ETHICS REVIEW COMMITTEE

Tel: +254 057 351 622 Ext: 3050
Fax: +254 057 351 221
Private Bag – 40105, Maseno, Kenya
Email: muerc-secretariate@maseno.ac.ke

FROM: Secretary - MUERC

DATE: 30th August, 2016

TO: Joash Oruta Nyakora
PG/PHD/NS/00008/2014
Department of Environmental Science
School of Environment and Earth Sciences
Maseno University
P. O. Box, Private Bag, Maseno, Kenya

REF: MSU/DRPI/MUERC/00315/16

RE: The Effect of Planted Riparian Buffer Vegetation in Protecting the Health of River by Analyzing Benthic, Macroinvertebrate Assemblages: A Case Study of Kuywa River, Bungoma County, Kenya. Proposal Reference Number: MSU/DRPI/MUERC/00315/16

This is to inform you that the Maseno University Ethics Review Committee (MUERC) determined that the ethics issues were adequately addressed in the proposal presented. Consequently, the study is granted approval for implementation effective this 30th day of August, 2016 for a period of one (1) year.

Please note that authorization to conduct this study will automatically expire on 29th August, 2017. If you plan to continue with the study beyond this date, please submit an application for continuation approval to the MUERC Secretariat by 30th July, 2017.

Approval for continuation of the study will be subject to successful submission of an annual progress report that is to reach the MUERC Secretariat by 30th July, 2017.

Please note that any unanticipated problems resulting from the conduct of this study must be reported to MUERC. You are required to submit any proposed changes to this study to MUERC for review and approval prior to initiation. Please advice MUERC when the study is completed or discontinued.

Thank you.

Yours faithfully,

Dr. Bonuke Anyona,
Secretary,
Maseno University Ethics Review Committee.

DIRECTORATE OF RESEARCH PUBLICATION & CONSULTANCIES
30 AUG 2016
MASENO UNIVERSITY

Cc: Chairman,
Maseno University Ethics Review Committee.

MASENO UNIVERSITY IS ISO 9001:2008 CERTIFIED