PHYSICOCHEMICAL WATER QUALITY AND MACROINVERTEBRATE OCCURRENCE IN SASALA STREAM RECEIVING WASTEWATER DISCHARGE FROM EARTHEN FISHPOND FARM IN KAKAMEGA COUNTY, KENYA

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A thesis submitted in partial fulfillment of the requirements for the award of Master of Science in Environmental Biology of Masinde Muliro University of Science and Technology

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DECLARATION

This thesis is my original work prepared with no other than the indicated sources and support and has not been presented elsewhere for a degree or any other award.

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance of Masinde Muliro University of Science and Technology a thesis entitled **"Physicochemical water quality and macroinvertebrate occurrence in Sasala stream receiving waste water discharge from earthen fish pond farm in kakamega County, Kenya".**

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DEDICATION

God of Abraham, and My Mother the Late Christine Mutuli; may her soul rest in eternal peace: Whom despite having no formal education inculcated in us the virtues of hard work and always encouraged us to pursue education for a better future. Through God's grace I have been able to reach where I am now and I have faith that the future is bright.

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Masaba J.L.M.

ABSTRACT

Fish farming is now a major source of global and local fish requirements of food, raw materials, income and ecological considerations supplementing the dwindling output from the wild waters. Several systems are now in place including use of earthen, concrete, liner ponds and race ways. Earthen ponds are of major concern as they mainly depend on natural stream water sources. The ponds release their effluents containing elevated levels of nutrients as a result of fertilizers and feeds used during pond management activities to the same streams. This study was done at a fish farm located along Sasala Stream within Lake Victoria North catchment. The objective was to assess the effect of discharge from earthen fishponds on the water quality of the stream using macroinvertebrates and the physicochemical state as indicators. The study intended to generate data and information that would be used by stakeholders, scholars, policy makers and natural resource managers to come up with strategies for sustainable aquaculture ventures. Sasala Stream is located in the outskirts of Kakamega town and supports a number of fishponds. Six sampling sites (marked 1 to 6) were established along the stream: one upstream; two were in ponds, each stocked with Nile Tilapia (*Oreochromis niloticus* and Catfish (*Clarias gariepinus*) respectively. Three sites were situated downstream after the ponds. Water and macroinvertebrates samples were collected in triplicate at intervals of fourteen days in the months of March to August. The samples were examined both in the field and the laboratory to determine the physicochemical state of Sasala Stream. Temperature, pH, Electrical conductivity, Total dissolved solids, Turbidity, Dissolved Oxygen were measured *in situ* with a Portable multi-parameter meter; Biological Oxygen Demand, Ammonia and Phosphate phosphorus were determined in the laboratory based on standard methods developed by The American Public Health Association,1998. Macroinvertebrates Species composition and diversity were determined using Shannon-Weiner and Simpson diversity Indices. The relationship between selected physicochemical parameters and between physicochemical parameters and macroinvertebrates was carried out using One Way Analysis of variance (ANOVA). In cases where ANOVA showed significant differences, Tukey test was used to separate the differences. Spearman rank order correlation was applied to determine the relationships between physicochemical parameters; and between physicochemical parameters and macroinvertebrates. All statistical analyses were done using Sigmaplot version 11. The means for the following physicochemical parameters were significantly different within the sampling sites. ($p=<0.05$): Dissolved Oxygen, Turbidity, Conductivity, Biological Oxygen Demand and Total Dissolved Solids. Ammonia values were 113.14μgl^{-1}in the upstream site and 431.57 μgl^{-1} in the catfish site. Phosphate-P values ranged between 1727μgl^{-1} in site 2 and 3 and 1692μgl^{-1} in site 6. From the observations earthen fish ponds discharge affected the water quality of the stream. Six Orders of macroinvertebrates comprising of 10 families were identified. Insects (83%), Non-insects (17%). *Baetis* sp. and *Velia* sp. dominated across the sampling sites while *Notonecta* sp. and *Chironomus* sp. were less dominant. Most of the macroinvertebrates families showed significant positive correlations with pH, TDS, Turbidity, Biological Oxygen Demand, ammonia and phosphorus. Sustainable fish farming will involve production systems that focus on the relationships between the culture techniques and the environment. Hence, regular monitoring of fish farms, good farm management and suitable planning of fish farms.

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ACRONYMS AND ABBREVIATIONS

APHA	-	American public health association
ASPT	-	Average score per taxon
BMWP	-	Biological Monitoring work party
BOD	-	Biological oxygen demand
DAP	-	Diammonium Phosphate
DFO	-	District Fisheries Officer
DO	-	Dissolved oxygen
EC	-	Electrical conductivity
ENPHO	-	Environmental and Public Health Organization
EPT	-	Ephemeroptera Plecoptera Trichoptera
ESP	-	Economic stimulus programme
FAO	-	Food and Agriculture Organization
FBI	-	Family biotic index
FFEPP	-	Fish farming enterprise productivity programme
GDP	-	Gross Domestic Product
MDGS	-	Millennium development goals
MMUST	-	Masinde Muliro University of Science and Technology
NAA	-	National Aquaculture Association (USA)
ORP	-	Oxidation reduction Potential
SASS	-	South African Scoring System
SGR	-	Specific growth rate
TDS	-	Total Dissolved Solids
TSS	-	Total suspended solids
USA	-	United States of America

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Despite the evidence of aquaculture waste water discharge having adverse effects on stream water quality, there is inadequate information in regard to the extent to which they participate in the deterioration of water quality in the Kenyan aquaculture situation. Particularly, the active relations between nutrients as a result of fish feeds, fertilizers and runoff water that have been a worldwide concern for many years. It is known that runoff directly transfers dissolved and fixed forms of total nitrogen and phosphorus into water bodies (Steinheimer, *et al*., 1998). Precise associations permitting predictions of macroinvertebrates community structure and in-stream physicochemical processes of streams receiving aquaculture waste water discharge is poorly understood.

Fish farming continues to grow rapidly globally calling for measures to ensure safety of the ecosystem from potential negative activities of aquaculture. (Fernandes, *et al.*, 2001).

Intensive fish farming activities entails the modification of dietary food into fish biomass, a process that generates wastes. In many instances the effects of the wastes on the ecosystem may be difficult to control and recover (Pandey and Satoh, 2006). The release of wastes in the form of effluents into aquatic ecosystem results in alterations of the receiving environment. The scale of effects that the wastes may have on the ecosystem relies as observed, on the types of feeds, feeding regime, aquaculture method, biological and physico-chemical behaviour of the receiving stream. (Akinrotimi, *et al.* 2010b). Reid, *et al,* 2008) observed that dissimilar water entities responds differently to entry of the same amount of wastes, and that fresh water and marine ecosystems are affected differently.

(Akinrotimi *et al*, 2011). Some of the effects are: direct toxicity on aquatic organisms, reduction in aesthetic value of the ecosystem, effects on fish groups, eutrophication, interstitial obstructions, poisonous microorganisms and reduced oxygen levels.

1.2Effect of physicochemical parameters on macroinvertebrates occurrence

Physicochemical factors (temperature, pH, conductivity, nutrient levels, TDS, biological oxygen demand and turbidity) control the occurrence and distribution of stream dwelling macroinvertebrates. These factors are influenced by several natural and human activities on the landscape that determine chemical characteristics and water quality of streams. Human actions for livelihood, including deforestation, agriculture, aquaculture, sand harvesting, urban run-off and discharge of untreated waters from sewers (Shivoga, *et al*., 2007; Njiru, *et al*., 2008; Onyando, *et al.*, 2013; Omofunmi, *et al*., 2016) result in changes in riparian vegetation of stream catchments hence determining stream water quality (Townsend, *et al*., 1997; Shivoga, *et al*., 2005 and Enanga, *et al*., 2011).

Landscape transformations are perhaps responsible for the widest spread damage to rivers and streams (Allan, 2004). The nature of a basin and the land use activity taking place within the watershed determines the physicochemical condition of a river or stream. Consequently, in lotic ecosystems, biological processes are directly linked with physical and chemical processes taking place in the catchment. For example, in intact forested areas, streams are thought to have usually good water quality with low dissolved nutrients and suspended sediments (Andrea, *et al*, 2009), because these areas are thought to efficiently cycle water with very minimum loses to the surface and ground water. Nevertheless, there are other land uses particularly roads and footpaths that take up small area of land but account for great percentage of total soil erosion (Ziegler, *et al*., 2001).In order to get a true indication of what happens within the catchment of a river or stream basin either during point or non-point sources of pollution, studies of spatial and temporal changes in water quality are crucial (Raburu and Okeyo, 2010).

Sasala stream drains an area of diverse gradient of land and water uses ranging from agriculture, aquaculture domestic water use and watering of animals. This study postulated that the diverse land use practices particularly aquaculture waste water discharge on a spatial scale have a direct effect on physicochemical conditions and therefore macroinvertebrates composition, abundance, diversity and distribution along the stream.

Related studies on interaction between physicochemical situation and macroinvertebrates in various Kenyan rivers have been done (Shivoga, 2001; Shivoga, *et al*., 2007; Kibichi, *et al*., 2007; Kibichi, *et a*l., 2008; Kigen, *et al*., 2009; Raburu and Okeyo, 2010; Enanga, *et a*l., 2011; Onyango, *et al*., 2013 and Onyando, *et al*., 2013).Nevertheless, none of the studies compared the effects of aquaculture waste water discharge from earthen fishpond farms. Studies have observed that aquaculture waste water discharge has adverse effects on water quality and macroinvertebrates assemblages in a river. Sasala stream is an important tributary of river Nzoia that drains into Lake Victoria.

Thus, it is vital to study the potential impacts of waste water discharge from earthen fishpond farms on physicochemical water quality and macroinvertebrates taxa composition, abundance and distribution receiving streams like Sasala stream.

1.3 Problem statement

Water quality and quantity of small streams is a key aspect in the sustenance of subsequent stream ecosystems, wildlife, aquaculture activities, domestic and livestock water needs. Currently, Sasala Stream, a head stream in the Nzoia River Basin of the Lake Victoria catchment provides water for more than 18 fishponds. Although the stream is of high ecological and social economic significance for the riparian community, no previous study has focused on the effects of aquaculture on the water quality of the stream, yet studies elsewhere indicate that uncontrolled anthropogenic activities (aquaculture included) may adversely affect the stream ecosystem. Some of the studies in Kenya and elsewhere are: Impact of land use on water quality of River Njoro (Shivoga, *et al*., 2007); Monitoring the health of large rivers (Jackson, *et al*., 2010).Assessment of pond effluent effect on water quality of Asuofia stream, Ghana(Amankwaah, *et al*., 2014).Impacts of discharge of effluents generated from Catfish ponds (*Clarius gariepinus*) in Southwestern Nigeria (Omofunmi, *et al*., 2016). Furthermore, the policy on fishpond establishment and management is not harmonized. Clear regulatory framework is lacking yet pond establishment and management activities such as construction, use of fertilizers, artificial feeds, hatchery management and production, introduction of exotic species and harvesting may have adverse influence on water quality of the downstream reaches of the stream or river. The study therefore intended to generate data and information on sustainable aquaculture ventures establishment, monitoring and management.

1.4 Justification

According to the United Nations environmental program, approximately one third of the people in the world are found in countries facing moderate to high water stress (George Ogendi and Ong'oa, 2009). In East Africa, Kenya is one of the countries experiencing water stress occasioned by increased population, land use changes and climate change. Currently one of the most significant environmental challenges related to water stress facing the government of Kenya is the declining quality of water (George Ogendi and Ong'oa, 2009). Unsustainable human activities like intensive agriculture, aquaculture, urbanization in watersheds are the major contributors to the deterioration of water quality of adjacent streams (Onyando, 2013). Although physical and chemical parameters have been used to monitor water quality in many streams in Kenya, no previous study has used biological parameters like macroinvertebrates and physicochemical state to monitor water quality in a vast majority of streams supplying water to fish ponds; yet aquaculture, a water intensive activity- (a standard fish pond of approximately, 300 m^2 holds approximately 255,000 litres of water) continues to be practiced along these streams. Reduced quality of water in the Sasala Stream will adversely affect the local population who use the stream water for drinking as well as the other aquatic life forms. Therefore, information generated from this study will not only be used by the scientific community, but also by government and other stakeholders in the development of regulatory, monitoring and management policy for sustainable aquaculture activities and the local community who depend on Sasala Stream for their livelihood.

1.5 General objective

To determine the effect of discharge from earthen fish ponds on the water quality of Sasala Stream in the Lake Victoria catchments, using physicochemical parameters and macroinvertebrates community structure as indicators.

1.5.1 Specific objectives

(i) To determine the effect of discharge from earthen fish ponds on selected physicochemical parameters of Sasala Stream.

(ii) To determine the effect of discharge from earthen fish ponds on macroinvertebrates species composition, abundance and diversity of Sasala Stream.

(iii) To determine the relationship between the physicochemical parameters and the composition of macroinvertebrates in Sasala Stream

1.5.2 Hypotheses

(i) Discharge from earthen fish ponds has no effect on physicochemical parameters of Sasala stream.

(ii) Discharge from earthen fish ponds has no effect on macroinvertebrates species abundance, distribution, diversity and composition of Sasala stream.

(iii) There is no relationship between physicochemical parameters and macroinvertebrates species abundance, distribution, diversity and composition in Sasala stream.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter reviews literature pertinent to this study. It also gives some of the results that have been obtained from related studies elsewhere in the world relative to the impact of aquaculture waste water discharge on water quality and relationship between water quality parameters and macroinvertebrates community assemblages in the receiving streams. It therefore brings out the knowledge gap that the study was anticipated to fill. The current general trends in global, Kenya and Kakamega County aquaculture production and the effects of related aquaculture management activities on stream ecosystem health is also highlighted. The main activities in focus are feeding of fish, fish pond fertilization and introduction of exotic fish species. Nature of Fish pond discharge and their effect on stream water quality. Sustainable management of aquaculture effluents. Ecological signals of stream health and studies using ecological indicators are also highlighted.

2.2 Aquaculture production

Fish culture has emerged as an important global human activity for ecological, economic and social reasons. In the year 2008, 52.5 million metric tonnes (MT) of fish were produced from fish culture representing 45.6 percent of the total world food fish consumption. Asia-pacific region is leading with a production of 89.1 percent of global production with China contributing 62.3 percent. The major aquaculture producing countries in Africa include Nigeria, Egypt, Uganda and Kenya (FAO, 2010). Farmed fish is one of the most important and cheap sources of protein for the current rapid global population growth (Akinrotimi, *et al.*, 2011).

Utilization of land in Kenya is classified based on agro-ecological regions (I-VI) (Appendix I). Classification of agro-ecological zones is arrived at by using a mixture of factors such as climate, soil type, vegetation type and topography. Agro-ecological zones (I-III) are the most suitable for fish farming. Available information suggests that aquaculture in Kenya was started by the colonial administration as a sport in the 1960's (Nyonje, *et al.,* 2011) and since then the sub-sector has undergone numerous changes. In the recent past a steady upward trend has been noted with increased funding from the government of Kenya and multilateral donors (Ngugi and Manyala, 2009). Currently, fish and fishery products exports raise over 5.3 billion Kenya Shillings (KES) yearly both from fish farming and fishing from the natural waters. The fishing industry is estimated to raise 5% of the Kenya's GDP which was projected to increase to 8% by the year 2015 (Ngugi and Manyala, 2009). Fish farming in Kenya is practiced in varied types of units ranging from Small hand dug 'Kitchen Ponds' to huge earthen ponds measuring 300 to 1000 m^2, surface area. In addition, dams and other abstractions which are used to store water are also stocked with fish and which are normally harvested partially or fully seasonally.

Currently, marine, brackish waters and freshwater are major habitats in which fish farming is carried out in Kenya. Fish species such as Nile Tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*) are the main cultured species in fresh water environment (Ngugi and Manyala, 2009).

Intensive, semi-intensive and extensive are the main fish farming systems in Kenya. Semi-intensive fish farming systems are mostly applied in the culture of Nile tilapia

(*Oreochromis niloticus*) and is the major contributor to aquaculture production in the country, producing on average 3 tonnes ha^{-1} and contributing 70% of the total fish production from ponds. Normally, organic and inorganic fertilizers in different ratios are used to fertilize the ponds to increase primary production. (Ngugi, *et al*., 2007; Ngugi and Manyala, 2009) Other supplementary formulated feeds mainly made from rice, maize, wheat brans, soy bean and fishmeal are also used. In some cases, mixed stocking of *Oreochromis niloticus* and *Clarias gariepinus* is done in differing proportions to control prolific breeding of Tilapia by acting as predators, feeding on tilapia young and eggs. (Ngugi and Manyala, 2009).

Production of fish in ponds had stalled at a yearly yield of about 1000 MT by 2006 (Ngugi and Manyala, 2009). The decline in fish production was attributed to various factors including inadequate extension services, poor quality fingerlings, expensive formulated commercial feeds reporting and documentation (Ngugi and Manyala, 2009). At the onset of 1999, following increased efforts in on farm research, training and extension, fish production improved to a production of 1500 MT in 2009 with a continuously steady increase going forward. The results of a National Aquaculture Inventory done between the years 2005 and 2006 showed that there were 7,500 fish farmers in Kenya with 7,477 ponds covering approximately 722.4 Ha of land surface. The mean yields from fish culture is estimated to be approximately 5.84 MT $Ha^{-1}/year^{-1}$ and was projected to rise to over 5200 MT $year^{-1}$ by the year 2015 if a production of 3% in annual growth is achieved (Nyonje, *et al.,* 2011).

The Government of Kenya through the economic stimulus program (ESP) identified fish farming as an activity aimed at spurring economic growth and national development in the year 2009. It was envisaged as one of the activities that would substantially create employment for the youth while enhancing economic growth and providing ready source of food fish and protein that would improve the health status of the people (Nyonje, *et al.*, 2011; Agano, *et al.*, 2017). The economic stimulus program was supported by relevant government policy papers, Millennium Development Goals (MDGs), Sustainable Development Goals (SDGs) and the Kenya Vision 2030 which has also considered aquaculture as one of the Flagship projects. Therein fish farming was identified among many other agricultural activities as one of the interventions that would be instituted to reduce the pressure on capture fisheries (Nyonje, *et al.*, 2011). The County Government of Kakamega, on the other hand due to high potential of aquaculture has embraced fish farming by supporting the venture through budgetary support. The Kakamega County Fish Farming and productivity programme supports fish farmers through provision of subsidized fingerlings and fish feeds. The current fish farming status is: 7851 fish farmers with 8396 fish ponds covering 2,226.9 Ha. Fish production is estimated at 6930 MT.

There is increasing need for fish and fish products world-wide (FAO, 2010). The current reports show that fish from wild sources is reducing drastically making fish farming the major remaining option to meet the anticipated shortfall (FAO, 2010). In the year 1980, world supply of fish from fish farming was a meager 5% of the total world production of 52.5 million Metric tonnes, 50% fish and shellfish in 2008 (FAO, 2010). The situation is no different in Kenya where fish farming was introduced in the 1950's by colonialists as a sport fishing activity (Nyonje, *et al*, 2011). In the year 2007, fish production from aquaculture was approximately 5.84 MT ha^{-1} $year^{-1}$ (Nyonje *et al*, 2011). This production represented 3% of the total national fisheries production before the implementation of the Economic Stimulus Programme. The major fish species cultured are the African Catfish (*Clarias gariepinus*) and the Nile Tilapia (*Oreochromis niloticus*). Currently, fish production from aquaculture in the country has risen to 12,000 metric tons valued at KES.1.8 billion (Nyonje, *et al*, 2011). This increase is as a result of the introduction of the Government support initiative through the Economic Stimulus Programme (ESP) as well as the launch of the Fish Farming Enterprise Productivity Programme (FFEPP). These two initiatives have continued to receive financial support from the Government of Kenya and multilateral donors. Fish farming has also been identified as one of the flagship projects under vision 2030 by the Government of Kenya. In western Kenya and Kakamega County in particular, fish production from ponds has increased and rapid growth of the sector has also been noted. In the year 2006, fish production from ponds was approximately 481,530 Kg while in 2011 the production rose to 21,063,600 Kg (DFO, Kakamega annual report, 2012).

Kakamega County received support for the construction of 2,700 new ponds, which were mainly earthen and liner fish ponds. The number of ponds is rapidly increasing as many people embrace fish farming as an economic enterprise. The ponds of average size 300 m^2 are constructed and stocked with approximately 1,000 tilapia or catfish fingerlings (artificially propagated-Catfish), of either mixed, hand sexed, hybridized or hormonal sex reversed (Tilapia) (DFO, Kakamega annual report, 2012).

The major sources of water for the ponds are: springs, streams, rivers, boreholes and rain water from roof harvesting. Prior to and after stocking with fish, the ponds are fertilized with animal manure or commercial fertilizers (NPK, Nitrates, Phosphates and Ammonium compounds). The fish are fed with both natural and artificial supplementary feeds containing both animal and plant proteins, carbohydrates, minerals and feed additives like lignin, beftonite, magnesite etc. Hormones are also applied during the process of sex reversal (Ovaprim, methyltestestrone, ostradiol). Fish are also treated with various types of medicines-tetracycline, amoxyline among others. (Akinrotimi, *et al*, 2011). The fish are normally harvested when they attain 150 grams and above after six months or more of growth.

Most of the ponds are based near springs, streams and rivers, and in their valleys. The Ponds are supplied with water from these sources and after the waters have passed through the ponds, waste waters and effluents are eventually discharged back into adjacent streams and rivers. The ponds are fitted with inlet, outlet and overflow pipes during construction to regulate entry and release of water. (Ngugi, *et al*., 2007). Fish culture activities generate large amounts of organic matter, nutrients, suspended solids which lead to adverse impacts on stream water quality including turbidity, oxygen depletion and eutrophication (Naylor, *et al*., 2000; Lin. K., Yi. Y. 2003; Abimorad, *et al.*, 2012). It is therefore important to study and establish the effect of aquaculture on water quality of streams receiving discharge from fish ponds.

2.3 The role of riparian zone in regulating water quality of rivers.

Some characteristics of the landscape that can moderate the physicochemical conditions within a river system include channel slope, vegetation on the banks and conditions of the riparian zone. Riparian zones are believed to act as ecological buffer zones that directly cushion a river channel from the possible adverse effects that can result from natural and anthropogenic activities taking place within the watershed. Therefore, shifts in the prevailing riparian vegetation can be expected to change the physicochemical and biotic integrity of streams (Townsend, *et al*., 1997). For example, in areas with dense riparian vegetation, the shading effect of riparian vegetation can result in reduction of the light intensity reaching the stream which influences the biological status of and the water temperature through a heat balance model.

Havel, *et al*., (1999) stated that a variety of spatio-temporal patterns observed in stream water quality in most catchments depend on land use history and hydrology while Johnson, *et al.*, (1997) observed that nitrogen concentration, alkalinity and TDS were more sensitive to agricultural land use during summer and underlying geology during autumn within the Saginaw River in Midwestern stream ecosystems, U.S.A.

Therefore, in order to understand the effects of riparian land use on the physicochemical conditions of a river, studies of spatial and temporal changes in the water quality are essential (Raburu and Okeyo,2010). In Kenya, some of the watersheds in which such studies have extensively been conducted include the River Nyando, Njoro, Isiukhu and Nzoia watersheds among others. However, in Sasala stream watershed, no such studies have been done despite the fact that this stream is a major tributary of River Nzoia and traverses an area of diverse land uses and supplies water to several earthen fish ponds and receives waste water discharge from the same fish ponds.

2.4 Nutrients (nitrate-nitrogen and phosphate-phosphorus)

Eutrophication refers to a boost in concentration of chemical nutrients in an ecosystem leading to amplified primary productivity. (Akinrotimi, *et al.*, 2011, Onyando, *et al.*, 2013). Eutrophication is in general brought about by nutrients input (i.e. cultural eutrophication) although at times occurs naturally. Aquatic life majorly depends on photosynthesis by algae and green plants. Excess nutrients accelerate growth of aquatic plants and algae. A range of sources of excess nutrients include wastes and fertilizers from agro-ecosystems (aquaculture included), faulty septic tanks and waste water treatment plant discharges.

In water, phosphorus is always the limiting factor for plant growth since it is exists in the lowest amount. Thus, excessive amounts of phosphorus in an aquatic environment can lead to increased vegetation growth and low BOD. Nitrogen can also be found in rivers in diverse forms including nitrates, nitrites and ammonia. Though, ammonia is rapidly changed to nitrates in aerobic waters and is associated with municipal treatment discharges. Its stressing effects enlarge at low DO levels and at increased pH.

Eutrophication in rivers causes both chemical and biological changes in the river system. For example, biologically, increase in nutrients concentration can result into algal blooms. These blooms can also cause increased phytoplankton, periphyton and macrophyte biomass that may obstruct recreational uses of a river e.g. boating, swimming and tourism. It also alters biotic community composition and decreases biotic integrity. (Akinrotimi, *et al*, 2011 and Onyando, *et al*., 2013).

2.5 Physicochemical conditions and macroinvertebrate assemblages

Aquatic macroinvertebrates are a group of invertebrates whose body width surpass 600µm including insects, worms and snails. (Griffiths, 1999). They are used as perfect biological indicators instead of microinvertebrates for numerous reasons. First, they spend most of their life in water and will only stay in areas that are fit for their continued existence and vary in tolerance to diverse amounts and types of pollution. Secondly, they regularly live for more than one year, which can be useful in depiction of conclusions about the reason of their death (Griffiths, 1999).

A good number macroinvertebrates are connected with stable patches of wood, logjams or rocky areas in silty and sandy rivers with uneven bottoms. The distribution and abundance of benthic macroinvertebrates communities entail numerous physical factors including water temperature, volume and velocity of water flow (discharge), substrates and energy relationships. This is because flow of energy and matter that provide food resources for stream residents is determined by the character of landscape behavior (Townsend, *et al*., 1997). Sasala stream which drains numerous land uses, providing water for a number of fish ponds. The stream also gets waste water discharge from the fish ponds. In this study it was postulated that there would be spatial changes in physicochemical environment and accordingly macroinvertebrates composition and distribution of the stream. Conversely, studies on these organisms within this watershed have not been done.

Consequently, it can be possible to assess the scope to which pollution from aquaculture establishments alters physicochemical factors and formation of biological communities in stream ecosystems by probing the patterns in the responses of benthic macroinvertebrates assemblages to possible stressors including nutrients and suspended solids connected with point source discharges (Makoba, *et al*., 2008).

A number of studies have been conducted to examine the influence of physicochemical situation of river waters on macroinvertebrates community assemblages. For example, Shivoga (2001) considered the influence of hydrology on the structure of invertebrate communities in two streams flowing into Lake Nakuru, Kenya and established that high human population density and unsuitable agricultural practices in the River Njoro basin not only resulted in increased water abstraction from the river for domestic use and irrigation, but also in erosion and consequently enormous inputs of sediments into the river. His study was restricted to Baharini spring brook and River Njoro, a second-order polluted river. Sasala stream on the other hand is a first-order stream that drains agricultural land and serves to supply water and receive waste water discharge from fish ponds.

Shehata and Badr (2010) reported that flow rate, water level, light and temperature were the key physical factors that control the form and numbers of phytoplankton in River Nile, and that biologically; Temperature and solar radiation play a significant role in the control of planktonic life. Temperature changes not only shape physiological processes of cells but also control the type of life present in water. Shehata and Badr (2010). The study was based on phytoplankton unlike the macroinvertebrates that my study emphasized.

From the above, it is clear that there are potential variations in water quality as a result of the changes in riparian land use practices, and changes in physicochemical variables which can influence the abundance, diversity and distribution of aquatic macroinvertebrates. This study, therefore, analyzed chosen water quality variables and assessed macroinvertebrates assemblages of Sasala stream in relation to discharge from earthen fish pond farm.

2.6 Potential effects of fish culture on stream ecosystem

Fish farming has been singled out for contributing to adverse environmental effects to adjacent water bodies. Therefore, scholars and the general public are advocating for proper management of aquaculture activities to prevent adverse effects of aquaculture to the natural ecosystem in question (Taylor, 2009).

The effects of aquaculture are mainly due to the type of fish farmed (species in context), placement of fish ponds, and magnitude of activities, morphology, limnology, hydrology, trophic status and assimilative capacity of water body where the discharge is released (Costa-Pierce, 1996; Cripps and Kelly, 1996; Boyd and Queiroz, 2001). Abu Hena, *et al*., (2004), report that fish ponds sited in fairly virgin watersheds may change the characteristics of the receiving water bodies extensively compared to those sited in large agricultural watersheds; moreover, growth and abundance of macroinvertebrates also relies on pond preparation, management and class of chemicals applied. There is no existence of policy nor legal framework to provide clear guidelines for placement of earthen fish ponds.

2.6.1 Direct toxicity on aquatic organisms

Wastes from fish farms comprise mainly nitrogen derivatives such as nitrite and ammonia. These compounds are harmful to aquatic organisms, fish included. (Green, *et al.*, 2001). Nitrite is known to hinder the oxygen carrying ability of haemoglobin, resulting in the oxidation of haemoglobin to methaemoglobin (Carnago and Alunso, 2006). Stephen and Farris (2004), noted that high ammonia levels can result into blood ammonia intoxication of fish leading to death, and damaging of downstream communities in streams where the discharges end up. Elevated ammonium levels leads to an ionic imbalance in the blood and acid-base distribution in the systems of fish (Twitchen and Eddy, 1994).

2.6.2 Reduction in aesthetic value of the ecosystem

Continuous release of fishpond effluents into the streams mainly from land-based fish farms have been observed to reduce the visual value of the stream environment Akinrotimi, *et al.,* 2009a). This is evidenced by rotten smell. The discharge from the ponds can increase occurrence of disease-causing organisms that arise downstream from the affected areas.

Increased human activity may disrupt habitats, breeding colonies and feeding grounds of indigenous species. Aquaculture units including fish ponds attract predatory species including birds, frogs, snakes and monitor lizards which prey on fingerlings, fry and adult fish. Whereas destruction of wetlands associated with the water bodies, may result in destruction of numerous biodiversity and reduction in the wetlands structure and functions.

2.6.3 Interruption of fish groups in the natural habitat

Interruption of fish assemblage in the natural environment is one of the effects of fish farm wastes discharges into the receiving streams. Oberdorff and Purches (1994) and Prevost (1999) described changes in the natural population of a variety of species of fish as a result of nonstop release of trout farm effluent into Brittanu rivers in Nigeria. Oberdorff and

Purches (1994) revealed that changes occurred in the index of biotic integrity based on 10 fish assemblages relative to high dissolved nutrient concentrations, due to discharge from trout farms. The fish assemblage changed to dominance by pollution tolerant and foreign species of *Rutilus rutilus* in the trout farm influenced areas; while pollution sensitive species such as *Cottus gobio* and *Salmo salar* were reduced in abundance.

Culture fish may also cause impacts on natural populations through interbreeding resulting in progenies that are poorly adapted to the ecosystem or interference with the existing genetic pool. There is also the likelihood of transfers or introduction of diseases (Courtenary, Jr., Williams, J.D. 1992).

2.6.4 Eutrophication

Stream ecosystems can demonstrate typical response or alteration in the river continuum when upset by nutrient rich fish farm effluents (Loch, *et al.,* 1996). Effluents with high organic loads confirm a dominance of heterotrophic bacteria and sewage fungi suppressing the primary production (Villanueva, *et al.,* 2000). The heterotrophic dominance is followed by an amplified primary production measured as chlorophyll. Inorganic total nitrogen and total phosphorous enrichment accounts for the rise (Fries and Bowles, 2002). The heterotrophic and eutrophic alteration is frequently accompanied by a modification in the macroinvertebrates community from intolerant species upstream of the discharge point to nutrient tolerant species, signifying an ecosystem ruin (Selong and Helfrich, 1998).

2.6.5 Interstitial obstruction and Substrate embeddedness

Suspended solids from fish pond wastes deposited in the receiving streams have been observed to cause interstitial obstruction and substrate embeddedness (Selong and Helfrich, 1998; Magni, *et al*., 2008). In the deposited sediments, heterotrophic bacteria show prolific growth leading to further interstitial clogging and de-oxygenation, as well as increase in colony-forming units (Carr and Goulde, 1990). This occurrence if left unabated will have toxic effects on the benthic organisms that are found in the receiving streams.

2.6.6 Production of poisonous micro-organisms and human diseases causing vectors

Regular flushing of fish farm effluents into the receiving streams have been observed to kindle the making of some noxious algae such as species of cyanobacteria, dinoflagellates and diatoms (Bureau and Hua, 2010). The toxins formed by algae can stay inside algal cells or may be released into the adjacent streams. Aquatic flora and fauna may be affected through intake of the water or ingesting algal cells through feeding activity. These algal toxins can also be bioaccumulated and biomagnified through food chains and food webs and reach toxic levels in some organisms meant for human utilization (Camargo and Alonso, 2006). Aquaculture wastes if not well controlled may be a medium for transferring human parasites and habitats of human disease carrying vectors. These may include mosquitoes, worms, leeches, bacteria. The diseases caused are malaria, bilharzias, typhoid fever, and cholera among others.

2.6.7 Decrease in dissolved oxygen levels

Discharge of fish pond wastes into the river ecosystems leads to overproduction of organic matter and its consequent decomposition typically results in low levels of dissolved oxygen in the bottom water strata and sediments of river ecosystems. Viadero, *et al.,* 2005) reported that characteristic values of dissolved oxygen content in trout farm effluent is between 1.26 and 3.2 mgl^{-1} and when released into the receiving stream it further reduces the dissolved oxygen values to below 0.5 mgl^{-1} particularly in situations with poor water mixing ability, which may impose a stressful state on fish (Schaperclaus, *et al.,* 1990; Mailland, *et al.,* 2005).

2.6.8 Effect of feeding fish and pond fertilization

Fish raised in ponds do not retain all the feeds that they are fed on in their body biomass. Some fragments of the feed get lost to the pond water as faeces, uneaten or unabsorbed feed and dissolved nutrients (Boyd and Tucker, 1998; Tucker and Hargreaves, 2003). The excess feed fragments eventually cause the levels of organic matter, suspended solids and nutrients in the pond to rise. There is need for data on the types of feeds used in the Kenyan aquaculture situation specifically the types of ingredients used during formulation of the feeds.

Macroinvertebrates found in streams and other water bodies consist of different groups of aquatic organisms, with a large number of species exhibiting a wide range of reactions to stressors like sediments, toxicants and organic pollutants (Maryland Department of Natural Resources, 1999). During harvesting of fish from ponds the preferred method is complete drainage of the pond releasing the wastes to adjacent streams. The receiving streams are adversely affected through high turbidity, elevated oxygen demand and eutrophication (Naylor, *et al*., 2000; Lin and Yi, 2003; Frimpong *et al*., 2004). (Zorriasatein, *et al*., 2009), have also reported that benthic production and abundance is a reflection of the effect of inorganic fertilizers. Ponds that are not cemented or lined contain large quantities of phosphorus and nitrogen which negatively affect freshwater ecosystems (Vallentyne, 1974; Setaro and Melack, 1984). According to (Odum, *et al.*, 1979), Subsidy-stress reactions in rivers and streams can be triggered by elevated nutrient enrichment, the ecosystem may show short lived good biotic characteristics from species richness and diversity indicator observations (Odum, *et al.*, 1979).

2.6.9 Potential effects of introduction of exotic fish species

Fish farming normally introduces new species of fish into ecosystems which are home to indigenous and other species of fish and other aquatic flora and fauna. The introduction causes biological pollution with adverse consequences to the native aquatic environment. Biological pollution can change composition of species and can also reduce species diversity (Courtenay and Williams, 1992; Mottram, 1996; Goldburg and Triplett, 1997). In addition, exotic fish species can be predators of endemic fish species and other aquatic life. Macroinvertebrates for example are sources of live feed with high protein content, fats, cellulose, lignin, starch, oils and waxes which may be predated upon extensively by the invaders. Introduced species are also competitors for food and space, alter or destroy endemic species habitats, and can bring in diseases and parasites (Krueger and May, 1991). On the other hand, fish farming has contributed to the transfer of 291 inland species from their native habitats into 148 countries (Welcomme, 1992).

2.8. Ecological signals of stream ecosystem health

Since aquatic organisms living in streams react to physical and chemical changes of their surrounding, aquatic biota are now increasingly being used alongside or instead of physical, chemical and toxicity tests to determine water quality. Protocols for water quality determination are now in use based on the principle that water systems which have not been disturbed structurally and functionally, have qualities that are fit with minimum treatment for different uses (Biney, 1997; Karr and Chu, 2000). Examples include streams whose carrying capacity for pollutants has not been surpassed. Normally, the cause-effect association between effluent and ecological effect is unclear (Tucker, *et al*., 2002). Information exist to the effect that aquatic macroinvertebrates provide dependable indication of impact of pollutants or habitat modification hence a good basis for direct bio-assessment and bio-monitoring (Karr and Chu, 2000). These methods using biological indicators are cheap and easy to apply in relation to chemical measurements and toxicological bioassays. In West Africa for example, biological methods have been successfully used in the Onchocerciasis Control Program where benthic macroinvertebrates were studied to monitor the impact of larvicides on river aquatic communities (Leveque, *et al*., 2003).

2.10. Biological indicators of stream ecosystem health studies

Several studies have used aquatic biota to determine the water quality of rivers and streams through the use of zooplankton, diatoms, protozoa, macroinvertebrates as well as fish (Gratwicke, *et al*., 2003; Smith, *et al*., 2006; Holeck, *et al*., 2008; Triest, *et al*., 2012;

Onyango, *et al*, 2013). Other examples where aquatic organisms have been used to monitor water quality in relation to anthropogenic activities are: aquaculture and recreation (Azrina, *et al*., 2005; Wahizatul, *et al*., 2006); Silviculture (Hutchens Jr. *et al*., 2004); aquaculture (Loch, *et al*., 1996); runoff from land clearing and urbanization (Arienzo, *et al*., 2001; Compin and Ce're'ghino, 2003; Iliopoulon-Georgudaki, *et al*., 2003; Makoba, *et al*., 2008; Onyando, *et al*., 2013), river impoundment (Ogbeibu and Oribhabor, 2002) organic and metal contamination (Grumiaux, *et al*., 1998).Water quality and bottom soil properties (Ndome, *et al*., 2012).There is need to carry out a study on impacts of aquaculture waste water discharge on receiving streams to complement the studies already done elsewhere. Hence, the current study.

Several aquatic biota may also be used to determine water quality but macroinvertebrates and fish are among the most preferred groups. Fish and aquatic macroinvertebrates inhabit almost all the stream ecosystem habitats bearing all the environmental changes that occur in those systems (Scardi, *et al*., 2006; Othman, *et al*., 2002). It is fairly cheap and easy to pick and classify fish and macroinvertebrates (De-Paw, *et al*., 2006; Scardi, *et al*., 2006), with various methods of data collection and analysis in existence (Hilsenhoff, 1977; Resh and Jackson, 1993; Brua, *et al*., 2011; Cao and Hawkins, 2011). Biological assessment is therefore a cost-effective method of determining water quality of streams in Kenya, a country that is in its early stages of economic development (Thorne and Williams, 1997).

2.11. Discharge from fish ponds

Discharge from fish ponds refers to water released from the out lets of ponds and consists of mainly uneaten food, faeces, urine, slime, chemicals and medicines used in pond management activities (Bergheinm and Asgard 1996; Sindilaru, 2007). The loads in the discharge vary considerably based on the species reared, the farming method and the water environment used. (NAA, 1998; Boyd and Queroz, 2001). Amirkolaie, 2011), divided the discharge from fish ponds into two major groups: solids and dissolved. The solid outflows are either able to settle or remain suspended. Brinker, *et al.,* (2005), reports that these solid outflows emanate from uneaten or spilled feed and from faeces. While phosphorus, ammonia, wastes from metabolic processes and other nutrients in the pond make up the dissolved-out flows. (Amirkolaie, 2011).

Brinker, (2008) observed that in a majority of fish farming practices 20 to 40 % of the dietary dry matter is used to build up the fish body during food absorption and the remainder is removed as faeces and urine. The quantity removed as uneaten or spilled food, is between 5 and 15% (Cho and Bureau, 1997; Ogunkoya, *et al.,* 2006). The total excreta in fish farming vary between 0.2 and 0.5kg dry matter in a feed and are influenced by fish species, farming method, feed composition, feeding regime, water temperature and culture medium (Chen, *et al.,* 1997; Bureau and Hua, 2010).

Effluent water from fish farming practices is usually discharged into adjacent streams. The quantity, regularity and composition of the wastes discharged with the effluent water differ among the diverse types of farming methods, and management practices applied (Tacon and Forster, 2003; Akinrotimi, *et al.* 2007b).

Concrete tanks, race ways liner ponds, earthen ponds, wooden ponds, cages and water recirculation systems are the major fish farming facilities used in Kenya. (Ngugi, *et* *al*.,2007).In stagnant and flow-through tank fish farming methods, all dissolved wastes and suspended solid are discharged on a regular basis into the environment during the production cycle. Alternatively wastes comprising of inorganic and organic particulate matter from earthen ponds are released occasionally or after harvesting, into the streams. (Akinrotimi, *et al*., 2007 C). Wastes from recirculation ponds are lower in comparison to those from concrete tanks and earthen ponds (Gabriel, *et al.,* 2009). Discharge from fish ponds on the other hand may also contain zooplankton and planktonic biota, chemical residues including medicines, feed additives, fertilizers, disinfectants and hormones depending on the fish farming method and pond management practices.

2.12. Measures to ease the effect of fish farm wastes on the adjacent stream ecosystem

The harmful effects of wastes from fish farms on the adjacent stream ecosystem do exist. Hence measures to facilitate control of the effects are critical to the sustainability of fish farming undertaking in Kakamega, Kenya.

These measures include but not limited to the following outlined below (2.61 to 2.67).

2.12.1 Appropriate setting up of fish farms

While establishing fish farms, there should be good planning regarding the subject of waste management actions. Milden and Redding, 1998) suggested that effluent handling possibilities ought to be included in the facility in the planning stage. This will help reduce effluent loads and make the treatment more efficient. A good example being use of dual drain tanks to concentrate settled solids into a smaller, more effectively treated flow, which lead to an overall improved effluent, (Summerfelt, *et al.,* 2004). At the planning level, some factors such as land topography, level of production, culture species and production function of the farm must be taken into consideration for efficient waste management. The level of urbanization of the farm site is also a rational matter, this means, that there must be effective planning, which must be based on good knowledge of the environment, such as water bodies, benthic conditions and the wider aquatic ecosystem as well as surrounding land areas (Akinrotimi, *et al.,* 2009).

2.12.2 Superior diet formulation

Digestibility of the ingredients and nutrient composition of the diet are the central factors affecting waste production in an aquaculture production system. Consequently, reducing waste yield from fish in culture medium should, therefore start at the source which is diet formulation and processing (Cho and Bureau, 2001). This is because, solid wastes in fish farm consists mainly of fiber from grain and plant ingredients that are not easily digestible by the fish. Reduction of solid wastes output from aquaculture operation can be achieved by using highly digestible ingredients with high protein and lipid contents (Bureau and Cho 2001) and excluding poorly digested grain by-products. This would increase palatability, digestibility and energy density of the feed and will go a long way in reducing the feed conversion ratio of the fish, thereby enhancing good body weight gain and as a result lowers solid wastes output in the culture medium (Bureau and Cho, 2010).

2.12.3 Improved feeding plan

Feeding tactic or regimes involves the method, rate, and frequency of feeding fish. The feeding tactic deals with alternatives to reduce the uneaten feed and increase feed efficiency. This is because feed wastage and feed ratio are highly correlated; leading to high levels in waste production at higher feeding rates (Van der Meer, *et al*., 1997). Hence for efficient management of waste production, *ad libitum* (general) feeding is not advisable. Feeding should be done based on standard feed chart for each species (Cho and Bureau, 1997) and should stop near satiation under close-look.

Different strategies have been used by many fish farmers to deliver feed rations to fish and also to monitor feed intake, so as to reduce feed losses in the culture medium (Cripps and Bergheim, 2000). Hand feeding is the oldest and most commonly used method in fish feeding, especially in the developing countries of the world. This may be an efficient technique in terms of conversion of feed into waste as feed delivery stops when fish approach satiation. There are other feeding methods such as fixed feed ration systems and demand feeders. The choice to be adopted according to Summerfelt *et al.,* (2004) is based on fish size, feeding behaviour, scale of operation and cost. However, demand feeders are suitable for a large-scale fish farm to deliver high rates of feed with the least amount of waste.

Feeding regimes in fishes are subjected to variations in feed ingestion in a day or between days, months or years (Jobling and Boardwith, 1991). for that reason, to lessen waste production, optimal time for feeding should be adjusted according to the day by day feeding activity of the species (Bolliet, *et al.,* 2001). For instance, in salmonids, feeding action is rigorous in the day (Helfman, 1993), whilst catfish feed more at night (Gabriel, *et al.,* 2007). Feeding regularity as well determines the rate of waste production in fish farming. Akinrotimi, *et al.* (2010b) reported that for optimum performance in the culture medium and to reduce waste production, farmers should not feed their fish more than three times in a day.

2.12.4 Practice of integrated fish farming

Integrated fish farming is a diversified and synchronized technique of farming with fish as major target (Ayinla, 2003). This involves combination of animal husbandry or crop with fish production in a farm concurrently. Akinrotimi, *et al.,* 2005) reported that in some parts of the Nigeria), particularly in the rural areas, there is mixture of fish production with planting of arable crops such as vegetables, whereby the effluents from the fish pond are released into the farm to serve as manures. This system promotes optimal utilization of resources and environmental sustainability. Moreover, Akinrotimi, *et al.,* 2010c) also observed that many species of vegetables can grow well in waste water discharged from intensive fish farms thereby reducing the nutrients and particulates loads to the surroundings.

2.12.5 Recycling of fish farming waste

The wastes excreted by fish in forms of dissolved nitrogen and phosphorous material can be re-used inside the system and converted into valuable products for the fish (Graber and Junge, 2009). When fish are fed, they can retain 20-50% Nitrogen feed and 15 – 56% phosphorous in feed (Shneider, *et al.,* 2004). The remaining of these minerals is released into the surrounding water and can be converted into useful items by phototrophic and heterotrophic organisms (Schneider, 2006). The bio-treatment of waste water with algae to eradicate nutrients such as nitrogen and phosphorous has long been known as a solution to change dissolved wastes into harvestable products (Komer and Vernaat; 1998; Verdegem, *et al.,* 2003). The alteration of nutrients into good products which can be utilized once more in fish production caused an important decline in the yield of dissolved wastes into the surroundings.

2.12.6 Good farm management

Effective management practices have been accepted as key to environmental sustainability of a fish farm (Akinrotimi, *et al.,* 2010d). This is based on the hydrographic character of the farm site and the degree of impact, which is as a result of assimilative and dispersive capacity of the farm location and production capacity of culture systems. Farm sites with good water exchange should be selected; if possible, in order to reduce fish farm related environmental impacts (Crozier, 2000). Good management practices should be practiced so as to minimize feed wastage and reduce environmental impact of aquaculture. Also, farms should be encouraged to have soak-away pits or artificial wetlands to reduce the discharge of farm effluents into the environment. The overall management of aquaculture operations should aim towards the development of best environmental practice, which can be defined as the implementation of procedures that would ensure the sustainable management of aquaculture.

2.12.7 Standard monitoring of fish farms

Monitoring practices must be adopted, which must be based on the species of fish, culture systems, culture techniques, nature and uses of the environment. Monitoring activities can be applied at different stages of the farming activities that are, pre-operational, operational or post operational stages and must consider the various interests of the public, regulators, farmers and scientists.

There should be regular monitoring of farms operations in aquaculture from time to time. The monitoring programme should target three main interest groups: the scientists, the regulators and the farmers, each of them are responsible for contributing and extracting different types of information (Fernandes, *et al.*, 2001). The regulator agencies are to develop easily enforceable best environmental practices that comply with the international standard, and set environmental quality objectives so that the environment can be monitored and regulated in such a way that these objectives would be achieved (Ackefors, 2000, Schneider, *et al.*, 2004).

The scientists in monitoring fish farms are to collect data from various farms, based on standard principles and methodology. They are responsible for keeping the monitoring programmes updated in terms of relevant research findings. From the farmers' point of view, the purpose of monitoring programme is to achieve affordable, applicable, useful and easily understandable best environmental practices, where farmers will be exposed to short- and long-term training to ensure that the farmer has up to date information and understands the implication of the farming operations (Maromi, 2000).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Overview

This chapter describes materials and methods that were used to test the hypotheses that:

(i) Discharge from earthen fish ponds has no effect on physicochemical parameters of Sasala Stream.

(ii) Discharge from earthen fish ponds has no effect on macroinvertebrates species composition, abundance and diversity of Sasala Stream.

(iii) There is no relationship between physicochemical parameters and macroinvertebrates species composition in Sasala Stream.

Both the status of physicochemical parameters and macroinvertebrates species composition in the stream were used to test the hypotheses. The study comprised of field and laboratory analysis of water and macroinvertebrates samples.

3.2 Study area

The study was conducted in Sasala Stream within the Lake Victoria catchment in Western Kenya (Figure 3.1). The catchment is located within Longitude 34° 3´ East and Latitude 34° 57´ 30´´ North at an altitude of between 1250 and 2000 meters above sea level. The Lake Victoria catchment falls within a tropical climate zone and experiences high rainfall from March to May and low rainfall from October to December (Mitchell *et al.*, 2009). The average annual precipitation is approximately 1,915mm (ranging between 1,387-2,573 mm per annum). Kakamega County receives approximately 1280 mm of rainfall per annum on average. The riparian zone of Sasala Stream consists of clay to sandy soils.

Sasala Stream is one of the tributaries supplying River Nzoia which eventually drains into Lake Victoria. The stream originates from a spring on the outskirts of Kakamega town in Kakamega County. One section of the tributary began from a protected spring that was a supply of water for domestic use like water for drinking, bathing and washing of clothes Sasala Stream is easily accessible and just like most other streams within the catchment, is preferred for aquaculture (Figure 3.2). There are several fish ponds along the stream which were constructed during the aquaculture economic stimulus programme in 2010.

The study sites are adjacent to Jafi Enterprises fish farm which draws from and discharges its waters into Sasala Stream. The farm has different types of ponds; thus, two liner, three round concrete ponds and five earthen ponds. The fish farm specializes in production of fingerlings for seed and 150grams and over for other consumers for hotels and home consumption. Tilapia (*Oreochromis niloticus*) and Cat fish (*Clarias gariepinus*) are cultured species on the farm. The fish farm has a modern hatchery using recirculation aquaculture system for production of fingerlings. The major fingerlings produced are the hormonal sex reversed Tilapia and artificially propagated catfish. The fish farm uses mainly artificially formulated commercial fish feeds of starter, grower and finisher categories. The ponds are constructed to the required standards with properly installed inlet and outlet pipes, to control water in the ponds. DAP an inorganic fertilizer was applied and left to stay for three weeks to enable primary production before the ponds were stocked. Harvesting of Table size fish is carried out after six months by draining the ponds and using a seine net to collect the fish. There are also other economic activities along the stream including maize farming, cassava growing, arrow roots and horticulture. The stream also serves as a source of water for domestic use by the riparian population and watering of cattle.

3.3 Sampling design

In the study, sampling sites and fish ponds were identified along Sasala Stream using systematic sampling technique (Figure 3.2). The number of fish ponds that were identified as sampling points, comprised a fraction of total ponds along Sasala Stream while the other sampling points were a fraction of the total length of the stream. In total Six sites were identified, one upstream before the fish ponds, one in Tilapia pond, one in Catfish pond respectively; and three sites downstream after the ponds (Figure 3.2). The three additional sampling points downstream were selected to determine the level of dilution of the discharge along the stream. The distance between the sampling points was approximately 20 m. Sampling on each of the sampling points was conducted at intervals of 14 days beginning from March to August, 2016. Sampling involved registration of selected physicochemical parameters *in situ,* collection of water samples for laboratory analysis and collection macroinvertebrates for identification in the Laboratory. Three samples were collected from each sampling point for each physicochemical parameter, water and macroinvertebrates on each sampling occasion.

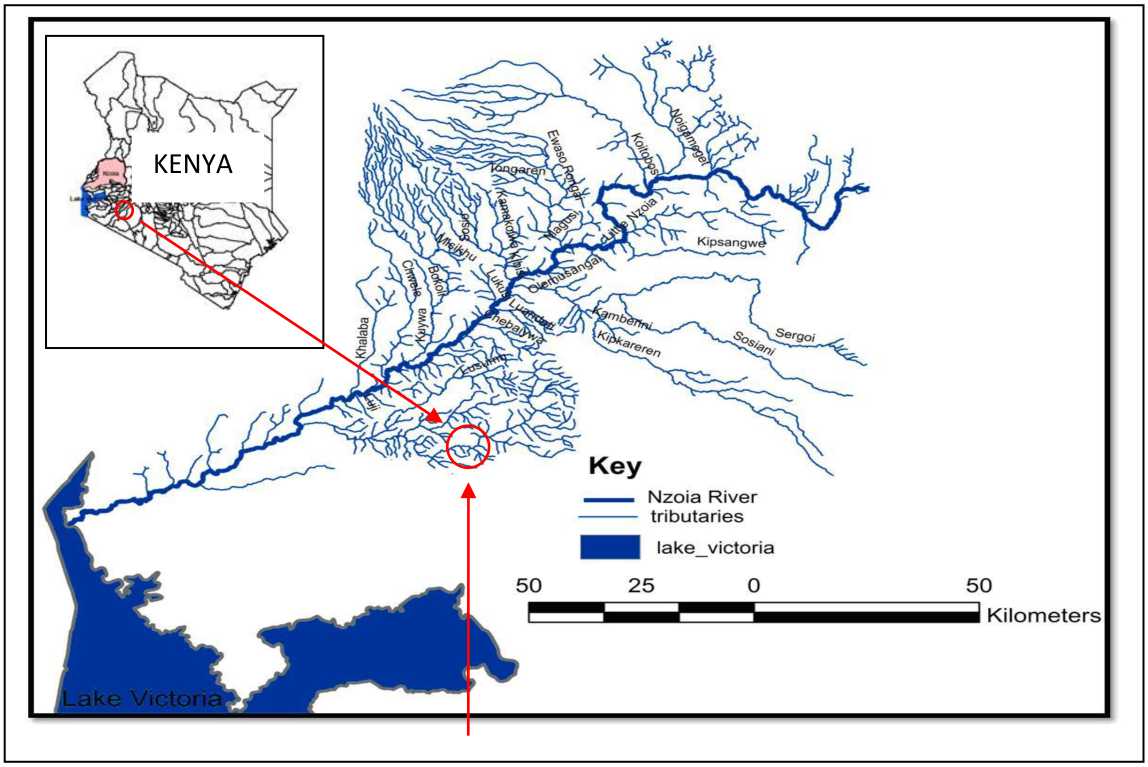

Figure 3.1: Lower basin of River Nzoia showing position of Sasala Stream (arrow and small circle). (See also Figure 3.2)
Source: Masibayi, (2011)

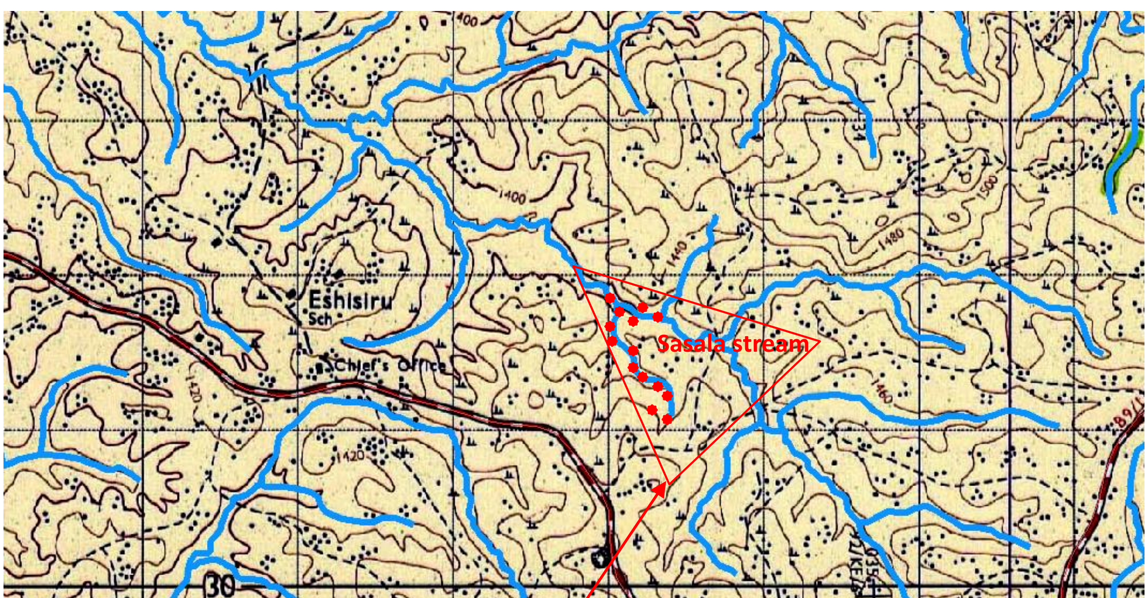

Figure 3.2: Topographical map excerpt of the study area with sampling points (marked in red dots) along Sasala stream (See also Figure 3.3)

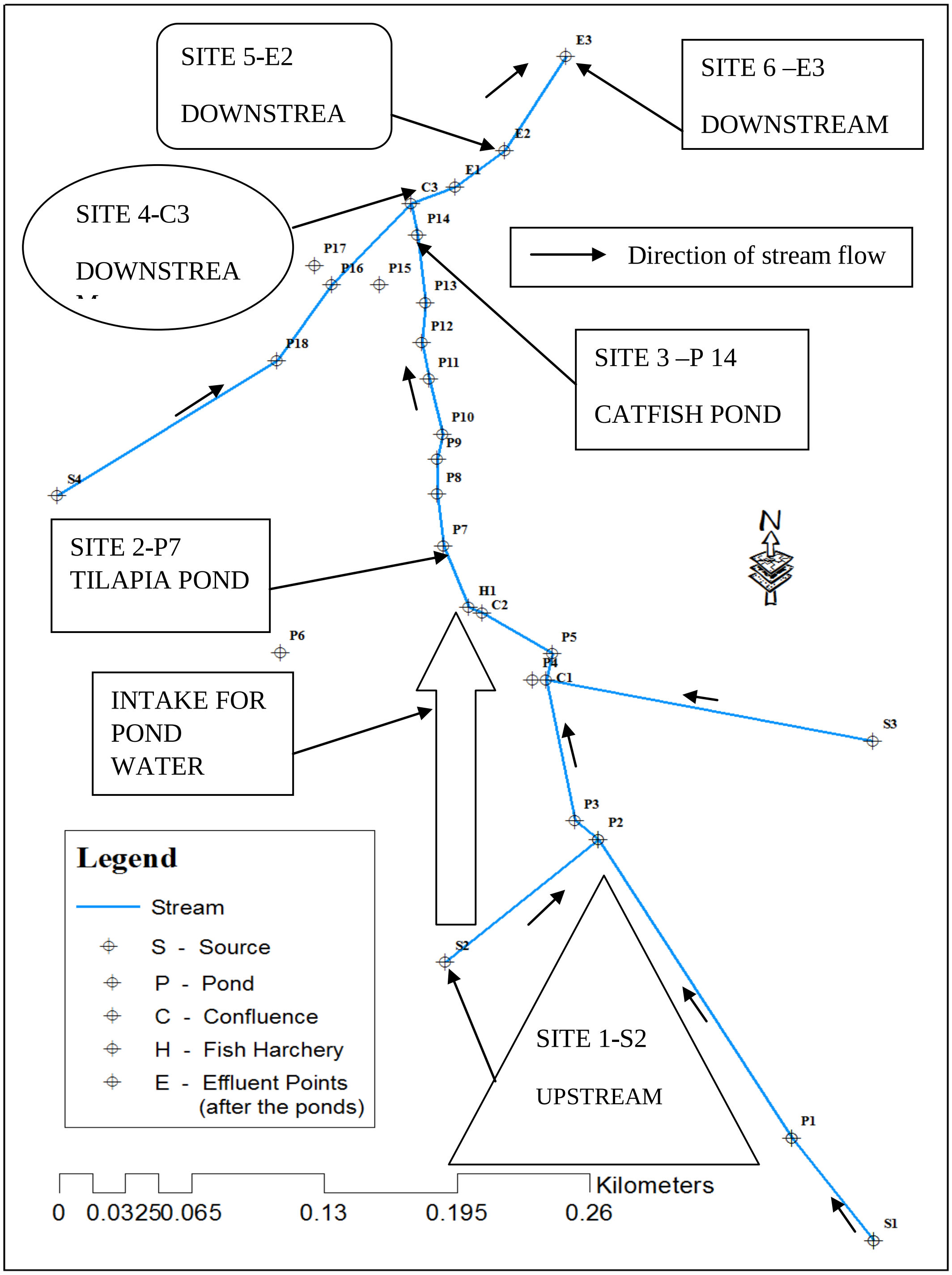

Figure 3.3: Diagram showing the position of study sampling points along Sasala Stream. (See Appendix II for GPS coordinates)
Source: Author, 2016

Table 3.1: The altitude, physical characteristics and land use of the study area with riffles, pools and runs summarized from microhabitats into habitats = stations of Sasala Stream during the study period

Site	Altitude	GPS	Land Use
1.	1400	$0^0$28'N $34^0$68E	Upstream(reference)
2.	1376	$0^0$28'N $34^0$68E	Tilapia pond
3.	1375	$0^0$28'N $34^0$68E	Catfish pond
4.	1371	$0^0$28'N $34^0$68E	Downstream 4
5.	1365	$0^0$28'N $34^0$68E	Downstream 5
6.	1367	$0^0$28'N $34^0$68E	Downstream 6

Plate 1: Sampling site 1

Plate 2: Sampling site 2 and 3

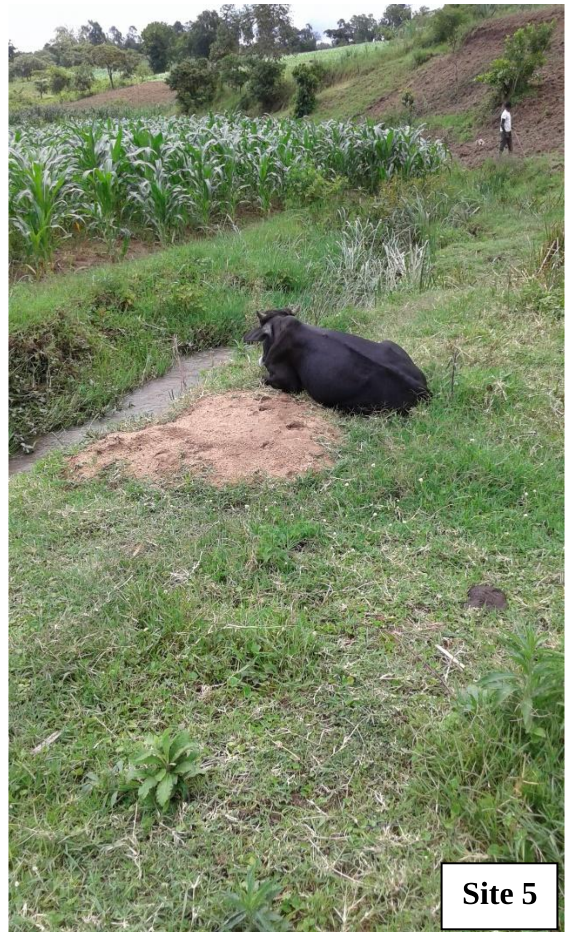

Plate 3: Sampling site 4 and 5

Plate 4: Sampling site 6

3.4 Determination of selected physicochemical parameters in Sasala stream

Determination of selected physicochemical parameters of water was conducted in the field and in the laboratory. Sampling for physicochemical parameters *in-situ* was done by starting from the downstream to upstream sites moving up systematically from site six (6) and ending with the upstream site (1). This was done to avoid possible interference with water parameters from physical disturbances. Sampling began in the morning through the afternoon at intervals of fourteen days. At each sampling site, triplicate readings of physicochemical parameters measurements were taken; water Temperature, pH, Dissolved Oxygen (DO), Electrical conductivity (EC), and Turbidity were recorded in situ using a Hydrolab (DKK-TOA Hand held water quality meter WQC-24) and Total Dissolved Solids (TDS) with an Oyster conductivity/Temperature Meter. In addition, triplicate water samples of 500 ml each were collected from each site and transported to the laboratory while stored in a cool box containing ice cubes.

Analysis of chemical parameters was conducted at the Zoology laboratory of Masinde Muliro University of Science and Technology (MMUST), in Kakamega.

3.4.1 Determination of Biological Oxygen Demand

Biological oxygen demand (BOD_5), phosphate-phosphorus (PO_4^{-3}-P), and ammonia-nitrogen (NH_4-N) determined using standard methods described by APHA (1998). To get BOD_5 levels, 300ml of collected water sample was filled into two BOD_5 bottles. Oxygen level in the first bottle was determined immediately while the second bottle was incubated in a dark cupboard for five days at 20^0 C.1N H_2SO_4 and 1 N NaOH was added to the sample to bring the pH to 7 and final oxygen level was determined using Azide modification of the Winkler method based on the account of Santhanam *et al*. (1989). 1 ml of concentrated sulphuric acid was added into the BOD_5 bottle using a micropipette after taking away the stopper. The BOD_5 bottles were then closed using stoppers and carefully tilted. A yellow solution was formed after dissolution of the brown precipitate that had formed earlier.200Ml of the yellow solution was transferred into a 250 ml conical flask and titration done against a standard sodium thiosulphate solution (0.025M) until a pale-yellow solution was formed. Three drops of 1% starch indicator was added and a blue color formed. Titration was done until the disappearance of the color marking the end stage of the procedure. DO in mg^{-1} is usually equivalent to the quantity of titrant used during titration. This is so as 1 ml of standard sodium thiosulphate has 1 mg^{-1} of DO. Level of Oxygen originally present in the sample equals level of iodine liberated.

3.4.2 Analyses for Soluble Reactive Phosphate-Phosphorus (Po4-P) And Ammonium-Nitrogen (Nh4-N)

Sample storage: The water samples were analyzed within 24 hours of collection while maintaining storage conditions of 5 °C in the dark. Distilled water that had been passed through an acid deionization-cation exchange resin was used throughout in a clean environment devoid of dust and smoke. Volatile cleaning agents, were used to avoid contamination of samples.

3.4.2.1 Soluble Reactive Phosphate-Phosphorus (PO_4-P) Determination

Soluble reactive Phosphate-phosphorus (PO_4-P) concentrations were determined using the Ascorbic Acid Method as outlined by Wetzel and Likens (2000).

The following reagents were first prepared as follows:

Ammonium molybdate solution: 15 g of ammonium paramolybdate $(NH_4)_6Mo_7O_24.4H_2O$ were dissolved in distilled water and diluted to 500 ml. The contents were stored in an amber polyethylene bottle and kept away from direct sunlight.

Sulphuric acid solution: 140 ml of concentrated sulphuric acid was added little by little to 900 ml of distilled water. The contents were stored in a glass-stoppered bottle at room temperature.

Ascorbic acid solution: 27 g of L-ascorbic acid (C_6H_8) were dissolved in 500 ml of distilled water. The solution was prepared for use then and there (prepared fresh daily).

Potassium antimonyl-tartrate solution (catalyst): 0.34 g of potassium antimonyl-tartrate [K(SbO) $C_4H_4O_6.1/2H_2O$] was dissolved in 250 ml of distilled water. The contents were stored in a glass bottle.

Composite reagent: The following were mixed together: 100 ml of ammonium molybdate, 250 ml sulphuric acid, 100 ml of ascorbic acid, and 50 ml potassium antimonyl-tartrate solutions. These were prepared daily for use and the excess discarded.

Phosphate standard solution: 0.2197 g of oven-dried (105 °C, 24 h) potassium dihydrogen phosphate (KH_2PO_4) was dissolved in distilled water and diluted to 1 liter. The solution was stored in a dark bottle with 1 ml of chloroform as a preservative.(100ml = 50.0 µg PO_4-P). The solution was diluted with distilled water as necessary to make appropriate standards.

3.4.2.2 Procedure for determination of PO_4-P concentrations

To water samples of 100 ml (15 to 30 °C), 10 ml of the composite sample was added from a 25 ml graduated cylinder and mixed thoroughly at once.

The mixture was left to stand for between 10 minutes to 2 hours. The extinction coefficient of the solution was measured in a 1 cm cell at a wavelength of 885 nm in a Spectro UV-11 spectrophotometer. The spectrophotometer was adjusted to zero reading using distilled water before measuring the extinction coefficient of the sample.

A standard curve was plotted by determining the absorbance (OD_{std}) in a Spectro UV-11 spectrophotometer, of four standard solutions (i.e., 10, 50, 100 and 500 µg l^1) diluted from the stock solution.

The standards were treated in the same fashion as the samples. A regression equation was obtained from the standard curve and values of concentration of PO_4-P (µg l^{-1}) of each sample was back-calculated from the regression equation.

3.4.2.3 ammonium-nitrogen (NH_4-N)

Ammonium-nitrogen (NH_4-N) concentrations were determined using the Indophenol Method as outlined by Wetzel and Likens (2000).The following reagents were first prepared as follows:Buffer: Trisodium phosphate (Na_3PO_4) in a 5% (W/V) solution.

Phenol stock: 500 g of crystalline analytical grade phenol were dissolved in methanol and diluted to 800 ml with methanol. The solution was stored under refrigeration in an amber bottle.27% NaOH: 270 g NaOH pellets were dissolved in de-ionized distilled water, cooled and diluted to 1 liter. *Phenate reagent* A: 0.02 g Sodium nitroprusside was added to 15 ml of phenol stock and diluted to 100 ml with de-ionized distilled water and the solution stored in an amber coloured bottle.

Reagent B: Equal volumes (15 ml) of sodium hypochlorite (fresh commercial bleach of 5% chlorine was adequate) and 27% NaOH solution were mixed and diluted to 50 ml with distilled water.

Reagents A and B were stored in amber bottles in a refrigerator; they were allowed to reach room temperature before using.*Ammonium standard*: 3.819 g of dry NH_4Cl were dissolved in distilled-deionized water and brought to 1 liter. 1.00 ml = 1000 µg NH_4-N. The solution was diluted serially for standards.

3.4.2.4 Procedure for determination of Ammonium-nitrogen (NH_4-N) concentrations

50.0 ml of distilled-deionized water (blank) ammonium standards and samples were dispensed into 50 ml graduated cylinders.2 ml phosphate buffer was added; and mixed. Any precipitate that may have formed was ignored. 5 ml of reagent A and 2.5 ml of reagent B was added and mixed well. The mixture was kept for 1 hour to allow for color development (stability was allowed at room temperature for 24 hours).

The optical density (absorbance) was read in a 1 cm cell at a wavelength of 630 nm, in a Spectro UV-11 spectrophotometer. The spectrophotometer was adjusted to zero reading using distilled water before measuring absorbance of the sample.

A standard curve was plotted by determining the absorbance (OD_{std}) of several standard solutions (i.e., 50, 100, 150, 200 µg l^{-1}) diluted from the stock solution.

The standards were treated in the same fashion as the samples. A regression equation was obtained from the standard curve and values of concentration of NH_4-N (µg l^{-1}) of each sample was back-calculated from the regression equation.

3.5 Determination of the species composition of macroinvertebrates of Sasala Stream

Macroinvertebrates samples were collected at each site in triplicate immediately after collecting water samples for physicochemical measurements. The Stream water was disturbed upstream by kicking using the foot. Macroinvertebrate samples were collected using a 500-µm mesh kick-net. This is a sampling net developed for multi-habitat sampling (MHS) and is better in efficiency compared to Surber sampler (Sharma and Moog, 2005). The net reduces the quantity of sediments in a sample and consequently the time for sorting. The disturbed macroinvertebrates in the stream were washed into the set kick net by the flowing action of the water. This was done for one minute in an area measuring approximately 1 M^2 as described by (Grant, 2002). Sieves of 500-µm mesh size were used to separate organisms from sediments. Large debris were removed from the samples after carefully washing off the attached organisms into a bucket and the water filtered through 250 µm mesh size sieves after hand sorting to separate the organisms from debris. Samples were taken randomly over the stream stretch at the sampling sites already determined. The samples were emptied into labelled 750-ml amber bottles and preserved in 70 % alcohol. All the collected macroinvertebrates in the kick net were emptied into a plastic jar that was half filled with 70% ethanol. The jar was labeled to include the date for sampling, sampling point and sampling sequence. Labelling was done using water proof labels and a permanent marker pen. Samples from all the sites were taken to the Zoology Department laboratory at the Masinde Muliro University of Science and Technology (MMUST) for counting. In the laboratory, samples were filtered through 250 µm mesh sieves, rinsed with distilled water into Petri dishes and sorted, identified and counted.

Species identification of the macroinvertebrates was conducted using a dissecting microscope (Leica Zoom model 2000, Leica Microsystems Wetzar, Germany) and a hand lens. All the voucher collection of macroinvertebrates was identified to the highest taxonomic level. IOWATER Benthic macroinvertebrate Key was used (Birmingham, *et al.,* 2005). The identified individuals were kept in plastic containers filled with 70 % ethanol for future use.

3.5.1 The diversity of macroinvertebrates was determined using Shannon and Simpson diversity indices

Diversity Indices: A diversity index is a mathematical measure of species diversity in a given community. It is based on the species richness (the number of species present) and species abundance (the number of individuals per species). The more the species present, the more diverse the area. There are two types of indices, dominance indices and information statistic indices. The equations for the two indices used in this study are: **Shannon Index** $(H') = -\sum p_i \ln p_i$ **and Simpson Index (D)** $= \sum n_i (n_i-1)/N (N-1)$**.** The Shannon index is an information statistic index, which means it assumes all species are represented in a sample and that they are randomly sampled. In the Shannon index, p is the proportion **(n/N)** of individuals of one particular species found **(n)** divided by the total number of individuals found **(N)**, ln is the natural log, Σ is the sum of the calculations, and s is the number of species. The Simpson index is a dominance index because it gives more weight to common or dominant species. In this case, a few rare species with only a few representatives will not affect the diversity. In the Simpson index, p is the proportion **(n/N)** of individuals of one particular species found **(n)** divided by the total number of individuals found **(N)**, **Σ** is still the sum of the calculations, and **s** is the number of species.

3.6 Relationship between Physicochemical Conditions and the Composition of Macroinvertebrates in Sasala Stream

The composition of macroinvertebrates was determined based on their species abundance and diversity. Assessment of macroinvertebrates composition was based on species diversity, richness and evenness, while their relationship with physicochemical parameters was determined based on the spearman rank order correlation coefficient.

3.7 Data analysis

Data analysis was done using SigmaPlot version 11. (USA). Non-parametric methods of data analysis were applied since both continuous and categorical data was collected. Descriptive statistics was conducted to determine the level of selected physicochemical parameters and to summarize species abundance and diversity of macroinvertebrates. The results were presented in form of Tables, pie charts and graphs.

The Spearman rank order correlation coefficient was used to determine the relationship between physicochemical parameters and abundance of macroinvertebrates. The one-way analysis of variance (ANOVA) was used to determine mean differences for the macroinvertebrate’s numbers at different physiochemical parameter factor levels.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Overview

In this chapter, results and discussion on the differences in physicochemical parameters, macroinvertebrate occurrences and their associations in Sasala Stream are presented.

4.2 Differences in physicochemical parameters

Significant differences were noted between physicochemical parameters in all the sampling sites along Sasala Stream. The sampling sites are arranged sequentially starting upstream site one (1), Site two (2) Tilapia fish pond, Site three (3) Catfish fish pond, and three sites downstream Site four (4), site five (5), and site six (6).The mean values and standard errors of the physicochemical parameters measured in the six sampling sites (1 to 6) in Sasala Stream are shown in Table 4.1.

Sampling period was from March to August 2016.Usually this area has two main rain seasons (heavy from March to May and light from October to November).

Table 4.1: Means (+/- SE) values of physicochemical parameters of water in Sasala Stream from March to August 2016. (N= Number of samples)

Parameter	N	Sites						P Value
		1	2	3	4	5	6	
pH	108	7.5±0.7	7.6±0.0	7.5±0.2	7.5±0.1	7.3±0.1	7.2±0.1	0.102*
Temperature (^{0}C)	108	23.5±0.5	24.2±0.7	25.4±0.6	22.8±0.4	22.8±0.4	23.2±0.4	0.005**
DO(MgL^{-1})	108	8.9±0.5	5.4±0.2	4.8±0.5	4.5±0.2	7.0±0.4	11.7±0.6	<0.001**
BOD_5(MgL^{-1})	108	4.0±0.05	2.3±0.2	2.02±0.1	3.3±0.1	3.3±0.1	4.0±0.1	<0.001**
Turbidity (NTU)	108	46.1±5.1	63.7±4.9	157.4±25	93.2±22.4	98.4±22	39.9±5.1	0.003**
E.C(µScm^{-1})	108	71.4±1.8	77.5±2.9	70.9±5.6	72.9±4.0	77.6±2.6	76.4±2.5	0.657*
Phos-P(µgl^{-1})	108	791.7 ±170.2	1730.6 ±32.2	1745.6 ±34.8	1286.9 ±216.2	422.2 ±63.3	518.6 ±68.8	<0.001**
Ammonia-N(µgl^{-1})	108	207.2±26	330.2±12	427.5±11	260±13.4	196.4±11	150.2±10.5	< 0.001**
TDS(MgL^{-1})	108	62.7±7.1	66.9±3.5	66.1±3.7	68.9±3.2	53.8±4.7	63.9±8.1	0.039**

* shows significant statistical difference

4.2.1 pH

The pH values recorded in the fish ponds (7.6 in tilapia and 7.5 in Catfish pond) were higher than in the other sites. In the fish ponds, during feeding of fish and pond fertilization; most of the uneaten feed end up decomposing in the ponds. The pH values exhibited a downward trend towards the downstream sites, (Figure 4.1). Overall, the pH was close to neutral which is a conducive environment for life of many aquatic organisms including fish, as well as most chemical reactions in the water.

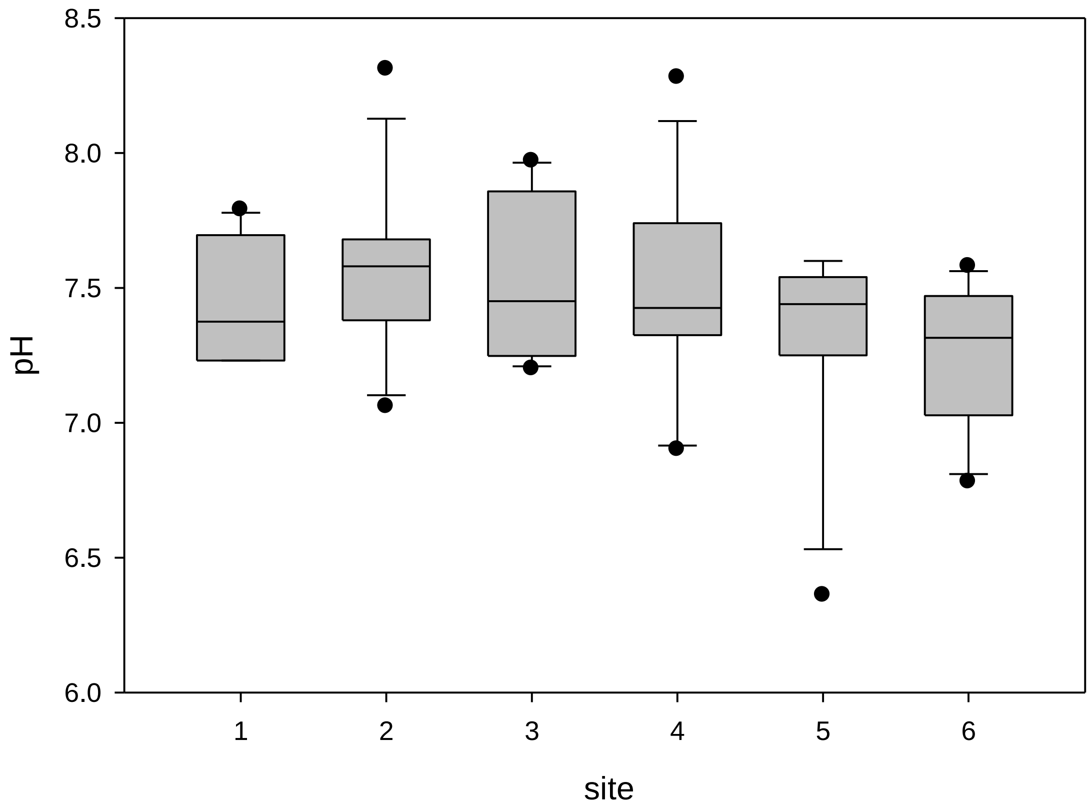

Figure 4.1: Box plot for variation in pH in Sasala Stream during the sampling period (March to August 2016). The median, percentiles (25th and 75th), 1.5 interquartile range and outliers are indicated

The pH values recorded in the Fish ponds (7.6 in the Tilapia pond and 7.5 in the Catfish pond). As reported by Agano, *et a*l., (2017). The critical pH for Tilapia growth is 3.7 and 11 while for optimal growth the pH values are 7 and 9. Tilapia. In the fish ponds, during feeding of fish and pond fertilization most of the uneaten feed end up decomposing in the ponds. The mean pH of the fish pond water ranged between 7.5 and 7.6. The values were close to neutral contrasting those in sewage waste water which are septic arising from breakdown of organic matter leading to production of acidic substances such as humic acids which reduces the pH. This agrees with Soonnenholzner and Boyd, (2000) who reported that oxidation of sulfide produced from sewage wastewater during microbial decomposition process leading to production of sulfuric acid creating acidic condition which could harm the culture fish species. The result also corroborates the observation of Babatunde and Woke, (2015) in waste water from fish ponds that is not well managed. Minor elevation in pH was not statistically significant (p=0.102). Even the pH in downstream of the earthen fish pond farm was still close to neutral as anticipated suitable for fish farming by different standard schemes (Lawson, 1995; Davis, 1993; Boyd & Gautier, 2000).

4.2.2 Temperature

The mean water temperature varied from 22.8 °C recorded in sites 4 and 5 respectively, to 25.4^{0}C at site 3 (Figure 4.2). Temperatures of 24.2^{o}C and 25.4^{o}C were recorded in the Tilapia and Catfish ponds respectively. These values were slightly higher than those in the sites upstream and downstream of the ponds (Figure 4.2). However, the temperature values were within the most preferred range for optimal growth of tilapia. Temperatures between 20^{o}C and 36 °C have been reported by different researchers as being appropriate for tilapia culture. According to Kausar and Salim (2006), for instance, the favored temperature range for optimum tilapia growth in ponds is between 25^{o}C and 27 °C. FAO (2011) reported the favored temperature ranges of between 31^{o}C and 36 °C, while Ngugi, *et al*. (2007) gave a range of between 20 and 35 °C as ideal for tilapia culture. This is consistent with the findings by Agano, *et a*l. (2017) in which the highest SGR of 4.4%/day for Tilapia was recorded at a water temperature of 35 °C in the control pond. The elevated temperatures could be due to sunlight heat absorption and retention by the more or less lentic habitat in the fish ponds and heat release by aquatic organisms like zooplankton and phytoplankton resulting from metabolic activities. Heat absorption from direct sunlight could be increased by turbidity due to suspended material resulting from fish feeding and swimming activities, particularly in the catfish pond. Decomposition of uneaten food in the ponds could also have resulted in the increase in water temperature. Fish ponds had a significant effect on water temperature (d.f =5; p=0.005).The separation of means indicated that the means of water temperature were statistically different ($p<0.05$).There were notable differences between sampling sites 3 and 6; site 3 and 1; site 2 and 6; site 2 and site 1. Elevated temperatures in fish ponds can also be ascribed to sediment heaps in the ponds as reported by Poole and Berman (2000). A rise in temperature of the water leads to the speeding up of the chemical reactions in water, reduces the solubility of gases and amplifies the odors (Trivedi & Goel, 1986). Aquatic organisms have both an upper and lower temperature limit for optimal growth.

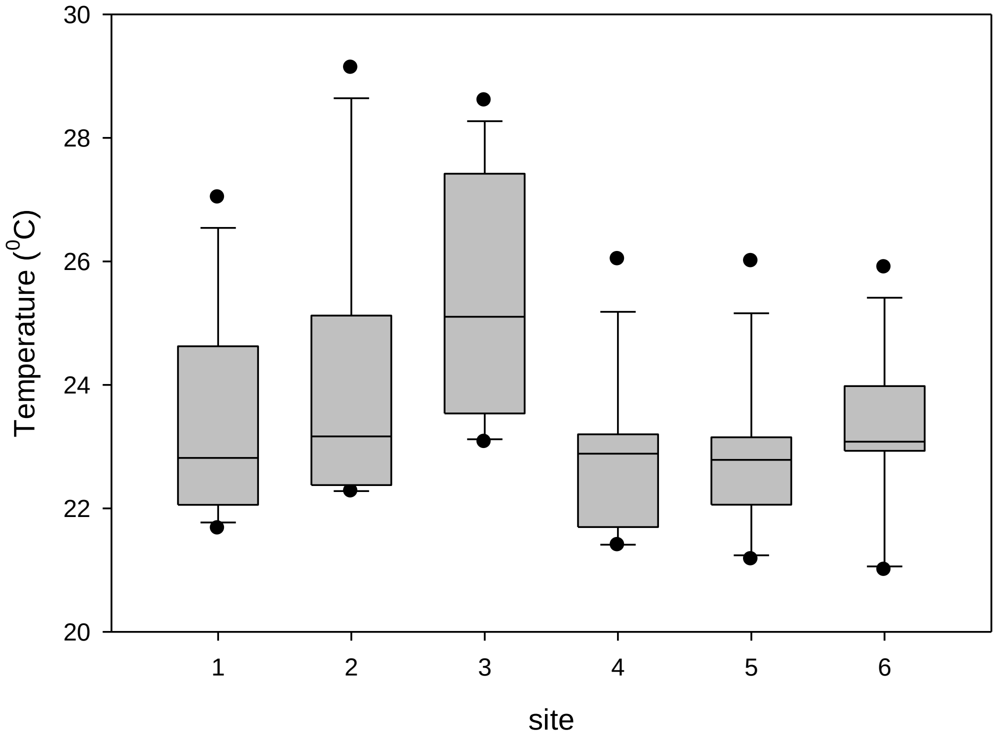

Figure 4.2: Box plot for variation in water Temperature values in sampling sites along Sasala Stream during the sampling period (March to August, 2016). The median, percentiles (25th and 75th), 1.5 interquartile range and outliers are indicated.

As water moves through a stream, its temperature changes as a consequence of numerous factors that interfere with the heat stability of water. The net increase or loss of heat by a stream as it moves through its course is the sum of the net radiation, evaporation, convection, conduction, and advection (Brown, 1983). In the tropics, net solar emission is a key control of a stream water heat balance and is usually dominated by the amount of direct-beam solar emission that reaches a stream surface. The lowest mean water temperatures were recorded within the downstream sampling sites which were characterized by a substantial vegetation cover along the stream. The shadowing effect of the riparian vegetation cover on the stream channel prevented direct heating of the water surface by the tropical sun. This agrees with Tabacchi *et al*. (1998),who observed that riparian flora has a shading effect on river channels therefore reduces direct water heating by solar power, leading to cooling by evapotranspiration from soil and water, and that forests play a big role by having elevated leaf area index. These results are also in line with the familiar observation that temperatures of rivers on spatial scale fluctuate depending on plants cover (Wetzel, 2001).

4.2.3 Dissolved oxygen

Dissolved oxygen varied from 3.93 mg O_2 l^{-1} in the fish ponds (site 2 and 3) to 14.47 mg O_2 l^{-1} at the last site (site 6) after the fish ponds. There was a significant difference in DO values among the sampling sites($p=<0.001$).DO was higher in the sites outside the fish ponds due to water flowing through the stream causing increased absorption of Dissolved Oxygen from the air. The DO in the ponds was low due to utilization of oxygen by the fish and phytoplankton in metabolism (Adam and Keith, 2012; Hamblin and Gale, 2002; Amankwaah, *et al*, 2014). High temperature, re-suspension of sediments distressing phytoplankton growth and productivity, decomposition of organic matter could have also led to lower DO levels in the ponds. Further, Hamblin and Gale (2002) reported that, the biological and chemical oxygen demand of wastes discharged from land-based aquaculture facilities can reduce DO concentration in lotic waters for short distances downstream. Oxygen is a vital parameter to the metabolism of every aquatic organism that possesses aerobic respiration. (Pulatsu, *et al*, 2004) Concentration of DO indicates water quality and its relation to the distribution and abundance of diverse algal species (Sisodia and

Moundiotiya, 2006). Its existence is fundamental to sustaining the advanced forms of biological life in the water (Trivedi and Goel, 1986). The DO in the water samples ranged between 3.5 mg/L to 14.3 mg/L in the sampling sites during the study period that was done in the wet season. Comparable outcomes were observed in Bagmati river system by ENPHO (1997) and Shrestha (2007). The study uncovered that DO at all sampling sites were above 4 mg/L and consequently, the water was appropriate for drinking, bathing, aquaculture and irrigation (Radhika, *et al*., 2004).

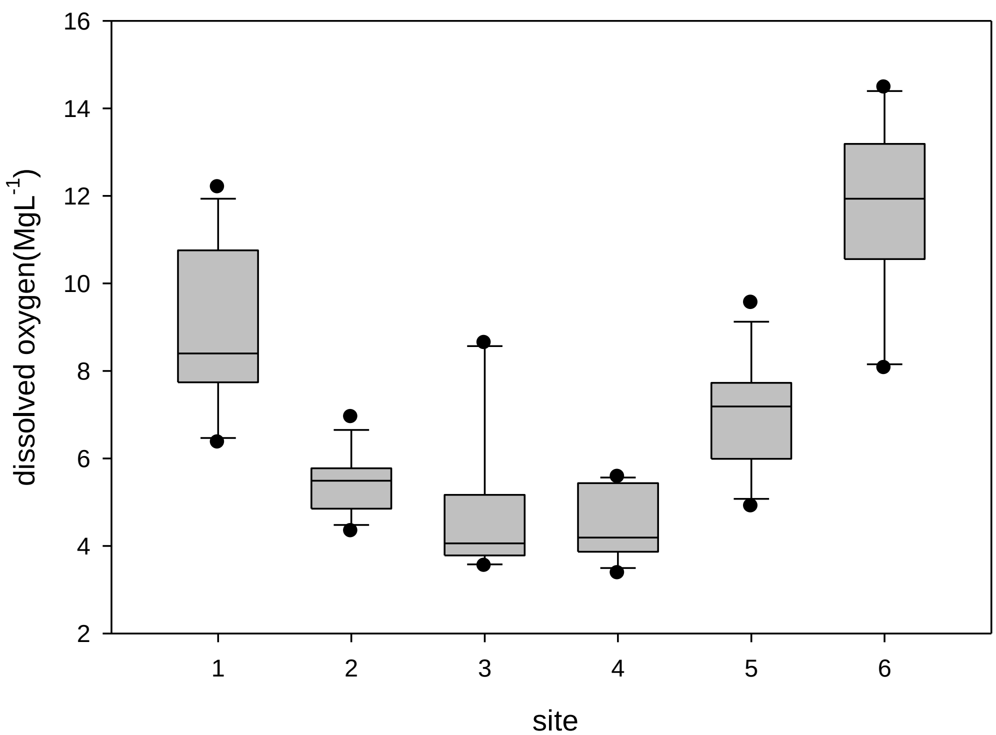

Figure 4.3: Box plot for variation in Dissolved Oxygen values in sampling sites along Sasala Stream during the sampling period (March to August 2016). The median, percentiles (25th and 75th), 1.5 interquartile range and outliers are indicated.

4.2.4 Biological oxygen demand

Biological oxygen demand (BOD_5) values ranged from 2.2 mg l^{-1} on average in the fish ponds to 3.95 mg l^{-1} in the upstream and downstream sites. The means of BOD_5 were significantly different (p=<0.001). These were generally low values indicating low organic waste pollution. Oxygen is required by fish and other aquatic organisms to live. The BOD_5 was found to be low during the sampling period. This may have been due to the high rainfall decreasing the concentration of organic load. Uncontaminated waters usually have BOD_5 values of 2 mg/L or less (UNESCO, 1996). The optimum BOD_5 range for fisheries and aquatic life is less than 15 mg/L (GoN/FDD, 1998).

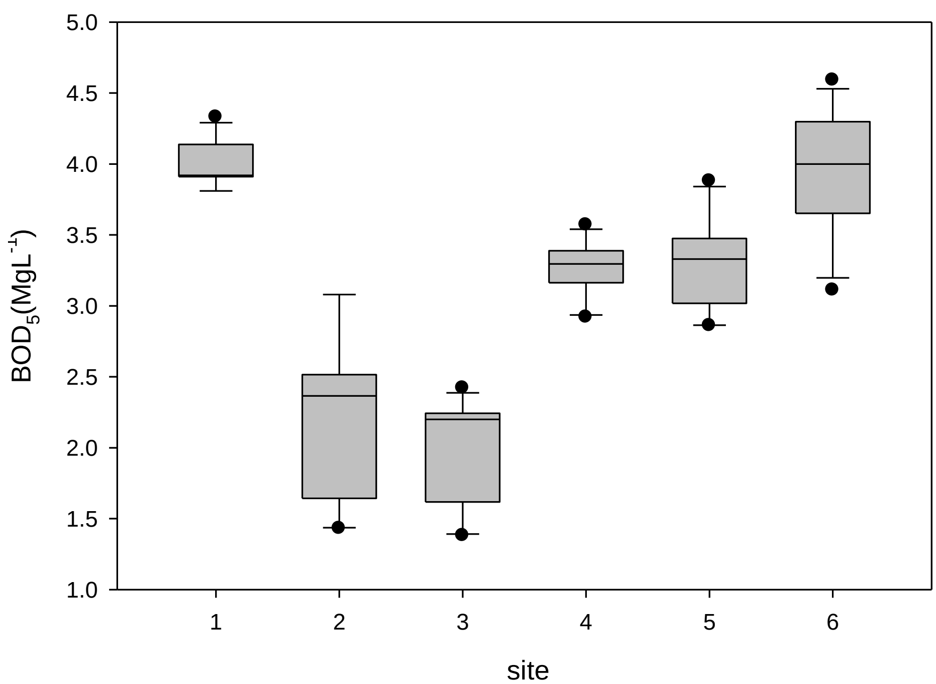

Figure 4.4: Box plot for variation in Biological oxygen demand values in sampling sites along Sasala Stream during the sampling period (March to August 2016). The median, percentiles (25th and 75th), 1.5 interquartile range and outliers are indicated.

A high waste discharge in organic matter and nutrients can lead to decrease in DO concentrations as a result of increased microbial activity occurring during the degradation of the organic matter. High content of BOD_5 cause oxygen depletion, which leads to the suffocation of aquatic life (Verma, *et al.* 1984). The values of BOD_5 in rainy period in all sites were recorded within the acceptable limits thus signifying existence of decomposable organic matter in the Sasala Stream area is suitable for aquaculture.

The rather low DO and BOD_5 in most sites sampled could be due to high decomposition of organic matter including unutilized fish feeds, organic manure and plant materials in the ponds.

4.2.5 Turbidity

The highest turbidity value 244.6 NTU, was recorded in the Catfish fish pond (site 3), while the lowest value 45.4 NTU was recorded at the site upstream (site 1). Turbidity values were generally higher in the fish ponds and decreased at the sites upstream and downstream. A significant difference was noted of the turbidity of the sites (p=0.003).

Turbidity was high in the fish ponds due to fish activity in the ponds, increased growth of phytoplankton due to pond fertilization, fish feeds that remained unutilized, feacal matter from the fish.

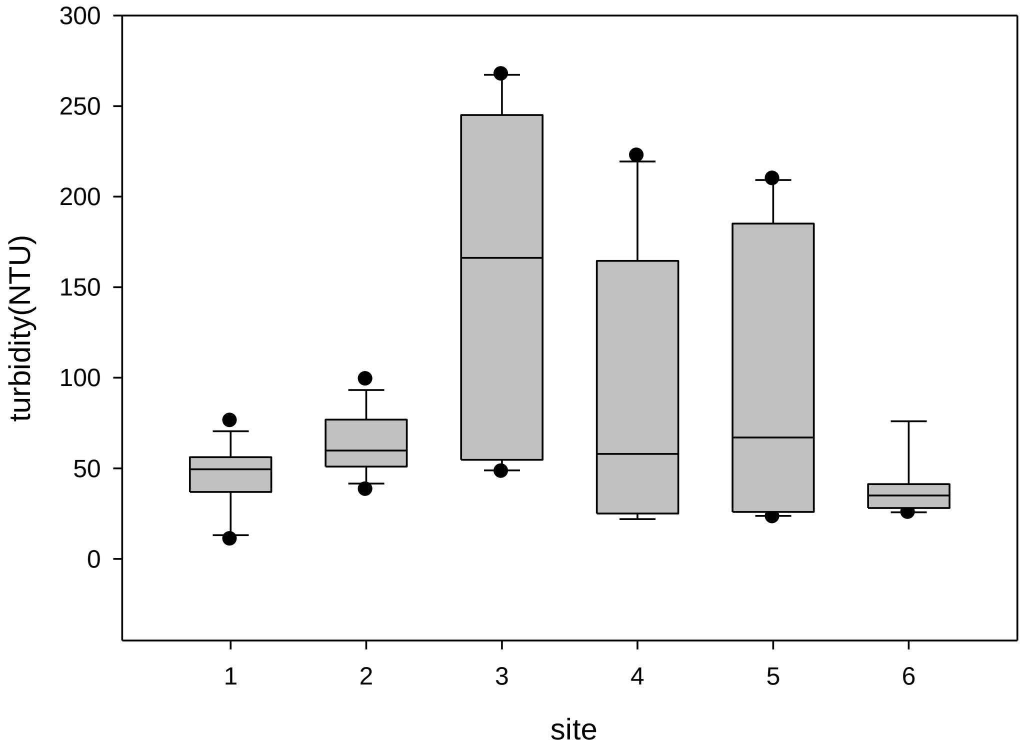

Figure 4.5: Box plot for variation in turbidity values in sampling sites along Sasala Stream during the sampling period (March to August 2016). The median, percentiles (25th and 75th), 1.5 interquartile range and outliers are indicated.

Silt, clay and other organic particles can suffocate larvae and clog gills of many aquatic organisms and interfere with their normal functioning or even cause death. They can also interfere with light penetration into the water column retarding growth of phytoplankton and macrophytes thereby lowering primary productivity and release of oxygen into the water, and life of other aquatic organisms. Silt, clay and other organic particles are also known to form attachment substrates for many types of bacteria and other micro-organisms. (Onyando, *et al.*, 2013; Payaswimi, *et al.*, 2017; Ehiagbonare, J.E and Ogunrinde, Y.O, 2010)

Sampling sites 3 and 4, showed poor water quality as compared to Sampling sites 1 and 6 due to receiving effluent of the fish farm as mentioned by Kamali, *et al*., (2009); Ghanesasansarai, (2004). Values of dissolved oxygen, turbidity, and TDS clearly indicated that effluents from the fish ponds polluted the stream. Increase in temperature, suspended solids (i.e., turbidity) and organic and inorganic solids, and decrease in dissolved oxygen and settlement of suspended solids on the river bottom are the physicochemical changes often observed in rivers and streams receiving fish pond effluents (Axler, *et al*., 1997; Jones, 1990; Selong and Helfrich, 1998; Bartoli, *et al*., 2007; Simões, *et al*., 2008; Ruiz-Zarzuela, *et al.*, 2009). In the present study, these physicochemical alterations were more evident in the ponds and generally after the fish ponds (Site 4 and 5) all downstream stations with a clear tendency to reduce with increasing downstream distance from the fish pond discharge points.

4.2.6 Electrical Conductivity

The lowest mean Electrical conductivity value, 70.9 μScm^{-1}, was recorded in the sites outside the ponds that is upstream (site 1) and increased gradually in the Tilapia pond (site 2) and catfish pond (site 3) to a mean value of 77.6 $\mu S\ m^{-1}$ downstream in site 5. Higher conductivity values were recorded in the Catfish pond. Statistically at 5 d. f there was no significant difference among the sites as the p=0. 657. This is due to inputs of dissolved substances including ions and mineral salts from feeds and fertilizer used in pond management activities.

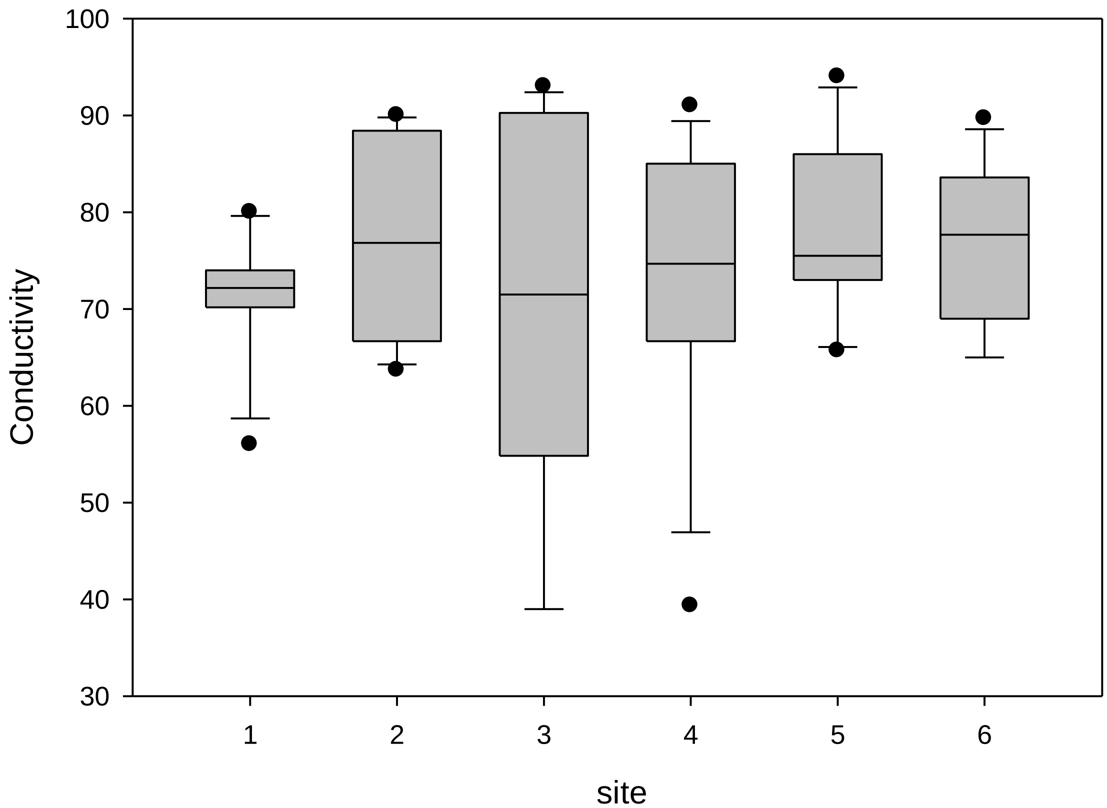

Figure 4.6: Box plot for variation in conductivity (μScm^{-1}) values in sampling sites along Sasala Stream during the sampling period (March to August 2016). The median, percentiles (25^{th} and 75^{th}), 1.5 interquartile range and outliers are indicated.

The ions may have also been as a result of fish activities (construction of nests for laying of eggs, or burrowing in search of food) that disturb the bottom of the pond releasing embedded substances that contain ions and minerals. Dissolution from the substrate due to waves by undercurrents in the pond. Surface overflow from agricultural actions and refuse from discarding sites close to the stream might add to the soaring electrical conductivity levels in the stream. Adam and Keith (2012) reported that surface runoff, effluents, minerals, and salts from town runoff during intense rainfall supply to elevated levels of electrical conductivity in receiving streams. The elevated electrical conductivity levels downstream can also be attributed to high levels of total dissolved solids, since electrical conductivity is a function of total dissolved solids (ions concentration) which determines the quality of water. (Tariq, *et al*., 2006). Conductivity gradually increased from upstream towards downstream which is similar to the findings of Boaventura, *et al*. (1997). Electrical conductivity is a measure of the ability of an aqueous solution to carry an electric current. It signifies the amount of TDS (Dahiya and Kaur, 1999). Conductivity is a function of TDS which determines the quality of water (Tariq *et al.*, 2006) This ability depends upon the presence of ions; on their total concentration, mobility and valence; and on the temperature of measurement (APHA, 1998). Runoff and precipitation determine the conductivity. Higher discharge lowers the conductivity and vice versa. All the values were higher than WHO guideline value (20-30 mg/L) in both dry and rainy seasons.

4.2.7 Total dissolved solids

Total dissolved solids followed almost similar trends like to those of electrical conductivity, and varied from 31.4 mg l^{-1} in sites before the fish ponds (site 1) and increased gradually in the fish ponds, (sites 2 and 3) to the highest value of 90.5 mg l^{-1} in the catfish pond (site 3). TDS then decreased gradually in the down stream sites 5. Like electrical conductivity ; Levels of TDS are influenced by dissolved ions and salts, in addition to micro-colloidal substances.

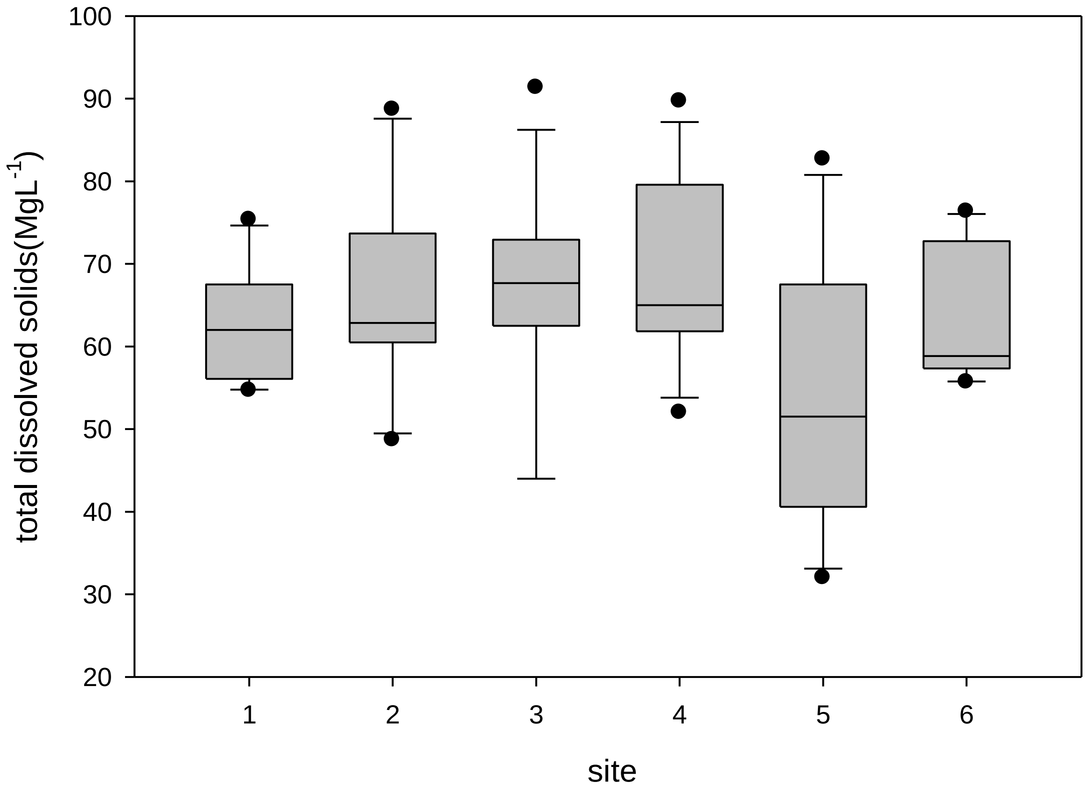

Figure 4.7: Box plot for variation in total dissolved solids values in sampling sites along Sasala Stream during the sampling period (March to August 2016). The median, percentiles (25^{th} and 75^{th}), 1.5 interquartile range and outliers are indicated.

4.2.8 Phosphate-Phosphorus

Phosphate-Phosphorus values ranged from 1727 µg l^{-1} in the fish ponds (sites 1 and 2) to 1692 µg l^{-1} in the sites outside the fish ponds (site 1,4,5and 6). Elevated phosphates in the ponds may have been as a result of pond management activities like fertilization and feeding.

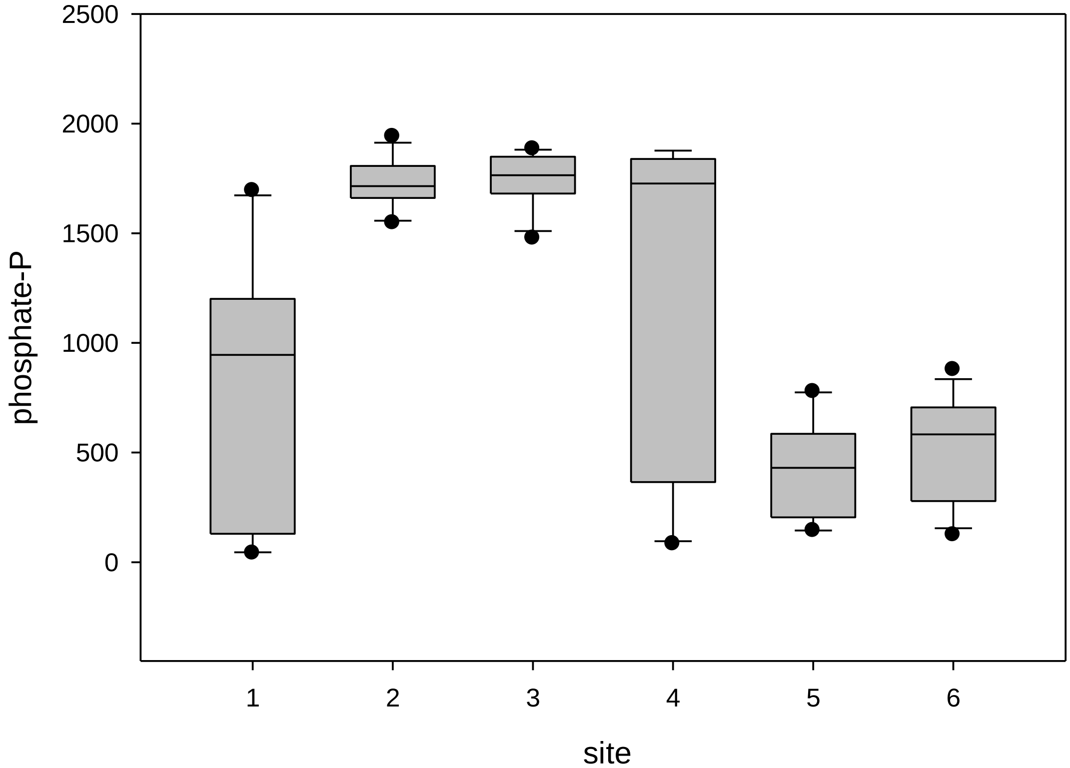

Figure 4.8: Box plot for variation in mean Phosphate-Phosphorus (μgl^{-1}) values in sampling sites along Sasala Stream during the sampling period (March to August 2016). The median, percentiles (25th and 75th), 1.5 interquartile range and outliers are indicated.

Disturbance of bottom of the ponds by the fish through nest creation and feeding and burrowing by Catfish may have led to weathering of the substratum. The fish feed and faeces might have contributed to the elevated levels of phosphate in the ponds. (Bureau and Cho, 1999) reported that, dissolved carbon, nitrogen and phosphorus are released into the water column by solubilization from feed and faeces and through the gill and urinary excretions of fish. According to Perry, *et al*, (2007), it is not possible to find high concentration of phosphorus if algae are already blooming, as the phosphates are incorporated in the algae tissue and not in the water. Phosphate-P is an essential nutrient for living organism and exists in water bodies as both dissolved and particulate species. In natural waters and waste waters, phosphorous occurs mostly as dissolved orthophosphates and polyphosphates, and organically bound phosphates (UNESCO, 1996 and APHA, 1998). Natural source of phosphorous in the wetland is due to the decomposition of organic matter. In most of the natural water, phosphorous ranges from 50 to 2000 µg /L^{-1} PO4-P. During the present investigation the highest concentration of phosphorous of 1883µg/L^{-1} was found at site 1.

4.2.9 Ammonia-nitrogen

Ammonia-nitrogen (NH4-N) ranged from 113.14 µg l^{-1} in the upstream site (site 1) to 431.57 µg l^{-1} in the catfish pond (site 3). Higher values of NH4-N generally occurred in the fish ponds. This may have been due to metabolic activities of the fish, pond fertilization and factors influencing availability of PO_4-P, and possibly through nitrogen fixation by cyanobacteria. The ammonium-N concentration in Ghol area was found to be high in rainy season and low in dry season.

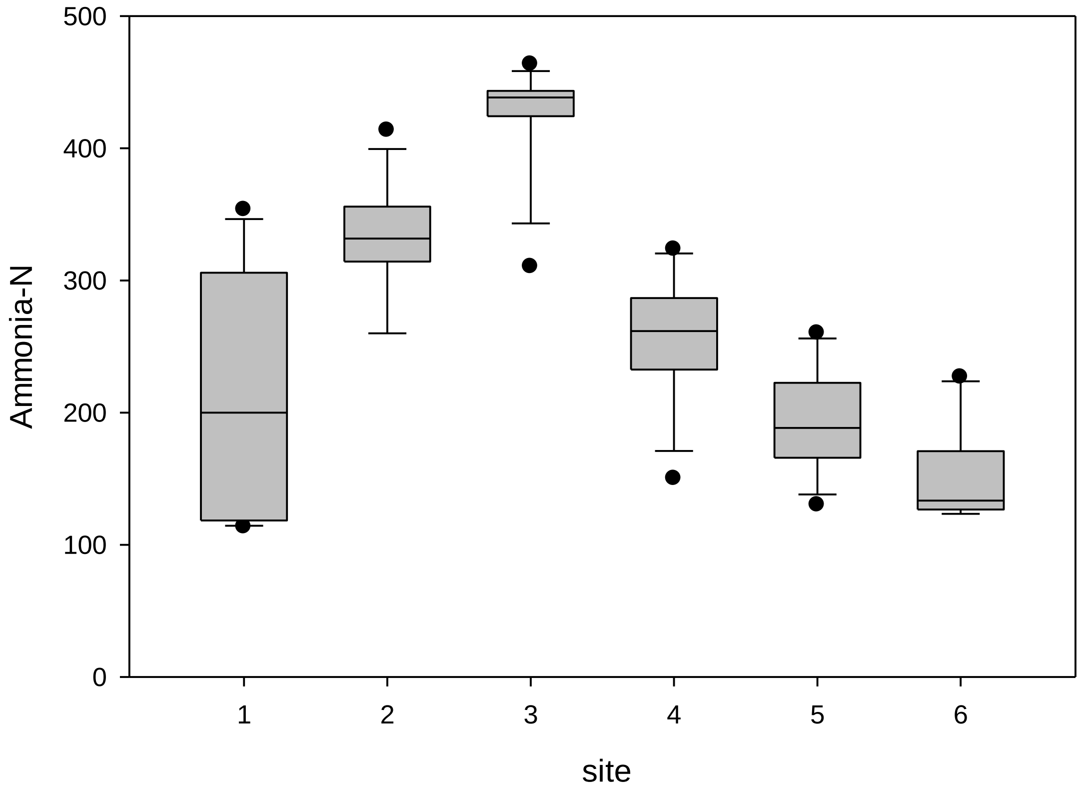

Figure 4.9: Box plot for variation in Ammonia-N ($\mu g l^{-1}$) values in sampling sites along Sasala Stream during the sampling period (March to August 2016). The median, percentiles (25^{th} and 75^{th}), 1.5 interquartile range and outliers are indicated.

The agricultural site contributed high ammonia concentration in rainy season. The values ranged from 2400 $\mu g L^{-1}$ to 2600 $\mu g L^{-1}$ in dry season and 2500$\mu g L^{-1}$ to 5700 $\mu g L^{-1}$ in rainy season. This result resembles the study carried out by Shahi (2012) in different lakes of Pokhara. In contrast the value was found opposite to the result of (Ali, 2002) where there is high ammonia value in dry season. They reported that the ammonia concentrations increase during hot period over cold seasons in toxic condition. The relative decrease in the ammonia concentrations during cold seasons were related to the oxidation of the ammonia by oxygen rich rather than uptake of ammonia by the phytoplankton cells (Shabana, 1999).

Unpolluted water contains small amounts of NH_3-N usually less than 1000 μgL^{-1} (UNESCO, 1996). Optimal ammonical nitrogen of water for fishes is less than 3000 μgL^{-1}. Highest limit of ammonia concentration for aquatic organisms is 100μgl^{-1}. (Santosh and Singh, 2007), while, Bhatnagar and Singh (2010) suggested ammonia levels of less than 200μgl^{-1} to be appropriate for pond fishery. This was consistent with the observation by Agano, *et al*., (2017), who found out that high specific growth rate for tilapia was in ponds with ammonia concentration of 100μgl^{-1} .Increasing pond aeration, regular water change, addition of quicklime are some of the ways farmers can use in managing ammonia within the ponds(Bhatnagar and Devi., (2013)

4.2.10 Relationship between physico-chemical parameters in Sasala Stream

Significant correlations were noted in some sites as shown in the table below.

Table 4.2. Spearman rank order correlation between physicochemical variables in Sasala Stream (Bold- Shows significant correlation at p<0.050)

Parameters	pH	Temp	DO	BOD	Turb	EC	TDS	NO_3-N	PO_4-P
pH									
	1.00								
Temp	**0.632**	1.00							
	0.000								
DO	-0.107	-0.076	1.00						
	0.370	0.525							
BOD	**-0.256**	**-0.378**	**0.613**	1.00					
	0.030	0.001	0.000						
Turb	-0.022	-0.041	**-0.496**	**-0.363**	1.00				
	0.857	0.730	0.000	0.002					
EC	-0.314	-0.006	-0.122	-0.023	-0.093	1.00			
	0.007	0.962	0.306	0.846	0.438				
TDS	0.220	**0.493**	-0.144	-0.119	**-0.377**	0.191	1.00		
	0.063	0.000	0.227	0.317	0.001	0.109			
$N0_3$-N	0.139	0.235	**-0.599**	**-0.759**	**0.374**	0.024	0.127	1.00	
	0.245	0.047	0.000	0.000	0.001	**0.843**	0.288		
PO_4-P	-0.073	-0.065	**-0.594**	**-0.565**	**0.395**	0.064	0.104	**0.641**	1.00
	0.542	0.588	0.000	0.000	0.001	**0.594**	0.385	0.000	

figures in bold shows significant correlation

Spearman rank order correlation showed numerous significant positive and negative correlations between physicochemical variables. (Table 4.2). There was a significant negative correlation between dissolved oxygen and temperature (r=-0.076; p=0.525).High water temperature seems to result in warming of the water leading to decreased solubility of oxygen. As the water temperature increased downstream of Sasala Stream, the amount of dissolved oxygen decreased. Elevated temperature may as well amplify the rate of oxygen consuming metabolic processes like respiration leading to the decline in oxygen concentrations. Related results were reported by Shehata and Badr, 2010) who established that in River Nile, temperature was negatively correlated with Dissolved Oxygen(r=-0.07). Temperature was fairly positively correlated with pH(r=0.6; p>0.000) in Sasala Stream. High water temperature increases Kinetic energy of the water molecules thus increasing the rate of dissociation of ionic compounds in the water structure, releasing extra hydroxyl ions that elevate the pH. Similar results were reported by Shehata and Badr (2010) in River Nile, Egypt.

Electrical conductivity was strongly positively correlated with TDS (r=0.191; p=0.109). High TDS levels raises the concentration of potential electric conductor ions in the water structure. Kaluli, *et al*., (2010), in a study carried out on surface water quality of urban environment in Githurai (Nairobi), Kenya, they observed a downstream increase in TDS in sections where conductivity was also very high.

Electrical conductivity was negatively correlated with water pH (r=-0.314;p=0.007) while TDS was positively correlated with pH (r=0.220;p=0.063). The three variables rely on concentration of ions in water. Elevated levels of hydroxyl ions in water, which increases the pH also raises conductivity. This explains the positive correlation between conductivity and pH. Several solids dissolve in water to produce ions, hydroxyl included, the ions conduct electric current. Hence the positive correlation between TDS and pH.

Temperature was positively correlated with phosphate-phosphorus (r=-0.065; p=0.588). High water temperature increases Kinetic energy of the water molecules leading to faster breakdown and dissolution of phosphate rich organic compounds, releasing this nutrient into the water structure. A process that is accompanied with discharge of a variety of other ions. Hence the positive correlation between conductivity and phosphate-phosphorus.

4.3 Variations in macroinvertebrate assemblages in Sasala Stream

During the study, 4647 macroinvertebrates were collected. The individuals comprised of 6 orders and 10 families, as shown in Table 4.2.

Table 4.3: Relative abundances of macroinvertebrates families at the sampling sites along Sasala Stream during the sampling period from (March to August, 2016).N=Number of samples

Order	Family	Genus	N	Sampling sites					
				1	2	3	4	5	6
Hemiptera	Belostomatidae	*Belostoma sp*	108	81	93	67	67	81	70
	Veliidae	*Velia sp*	108	155	201	84	112	155	71
	Notonectidae	*Notonecta sp*	108	0	59	37	50	0	30
	Hydrometridae		108	0	107	27	25	0	59
Ephemeroptera	Baetidae	*Baetis sp*	108	97	190	206	249	97	168
Odonata	Gomphidae	*Gomphus sp*	108	118	76	32	90	91	69
Coleoptera	Gyrinidae	*Gyrinus sp*	108	110	0	30	72	84	86
Gastropoda	Physidae		108	0	67	153	87	0	32
Diptera	Chironomidae	*Chironomus sp*	108	0	99	25	205	0	78
	Arachnida	*Arenae sp*	108	0	86	189	48	0	82

Veliidae was the most common macroinvertebrates family appearing in all the sampling sites in big numbers during the sampling period (Table 4.3). This is because this family comprises of active swimmers that are relatively tolerant to pollution(Onyando, *et al*., 2013). They colonise most sites and in the case of this study even the fish ponds and downstream sites where the habitat conditions have been degraded. Veliidae (Hemiptera), Hydrometridae (Hemiptera), Baetidae (Ephemeroptera) Notonectidae and Arachnida (Diptera) were very common within the fish ponds in large numbers. Veliidae a family of active swimmers and can hence inhabit even courses of the stream with high velocity of currents. Active swimmers are less likely to be solitary colonizers and parthenogenesis is accordingly less of an advantage (Wiggins, *et al.*,1980).The wide distribution of these Hemipterans due to migratory ability appears to have evolved in taxa whose habitats are sometimes that are not conducive for breeding, those with the most ephemeral breeding habitats having higher powers of dispersal than species in permanent habitats.

The population of Baetidae was highest within the fish ponds probably due to low velocity of the water. Since Baetidae feed on small crustaceans, insect larvae and oligochaetes and are also phytophagous, they are the best suited of all aquatic Hemiptera to the food resources of cool waters, particularly in low velocity areas.

Members of the families Hydrometridae,Chironomidae and Notononectidae occurred in high numbers only within the ponds with very low relative abundances in the downstream and upstream sites. (Table 4.3). Chironomidae are Some of the tolerant taxa with tolerance values 2-3 (Blakely, *et al.,* 2014). According to Jackson, *et al.,* (2010) and Płociennik & Karaouzas (2014), Chironomidae are highly tolerant to organic pollutions, and they choose relatively soft bottom sediments. Generally, Chironomidae larvae have haemoglobin that helps transport and store oxygen in low oxygen environments (Barbour, *et al.,*1996; Cranston 2004).The results of this study correspond to previous findings by Sriariyanuwath, *et al.,* (2015) who reported that Subfamily Chironominae were very tolerant in study sites with high value turbidity, EC, TDS and Phosphate-Phosphorus Whereas, Gyrinidae occurred in relatively large numbers in the upstream(1) and downstream sites(6). This is because these taxa are sensitive to environmental pollution that degrade habitat quality. The fish ponds and downstream sites had various anthropogenic activities that result into release of materials into the river channel degrading water quality. This change in percentage composition of the taxa is similar to that reported in studies elsewhere. Van Someren (1952) revealed that within high altitudes of Mount Kenya, benthic macroinvertebrates communities of Naro-Moru, Barguret, Sagana and Sirimon streams were dominated by Baetidae and Simulidae. Mathooko and Mavuti (1992) also reported that Baetidae and Simulidae were the dominant taxa within the same sites while Kibichi, *et al.,(*2007),found that Baetis and simulidae taxa comprised 69% of the macroinvertebrates collected in River Njoro Watershed, while Raburu, *et* *al.,(*2009) found that Ephemeropterans had the highest relative abundance constituting more than 50% of the macroinvertebrates.

In contrast, Ahmel-Abdallah, *et al.,(*2004) reported that Potamon sp.(fresh water crab) dominated the benthos in Tanzania upland streams. The ability of Baetidae to dominate across the sites including the fish ponds can be attributed to its ability to tolerate habitat degradation due to human activities.

Allan (2004) made similar observations and concluded that alterations of land use in a water shed lead to changes in physical habitat conditions that directly impact on the dynamics and arrangement of stream habitat features on a spatial scale. Stuart and Davies (2005) also reported that spatial variations in the structure of benthic communities are the direct response of the fauna to changes in abiotic conditions.

Belostomatidae, Valiidae, Physidae and Baetidae were present in the fish ponds in high relative abundances because of the high levels of suspended solids and organic matter within the sites. This further explains the significant positive correlation between this family and turbidity ($p=0.060$ and BOD_5 ($p=0.016$).

Bottom-dwelling macroinvertebrates family Physidae were present in large numbers in the fish ponds(2 and 3) and some downstream sites(4). This is probably because these sites are rich in organic matter from which the family derive nutrients. Effect of substrate on benthic macroinvertebrates is determined by substrate size, organic content and interaction with other environmental factors. Substrates do not only harbor different assemblages of organisms, but also affect the density, biomass and diversity of benthic macroinvertebrates. This family is bottom dwelling and therefore prefer places where the stream bed provides suitable physical habitat conditions. Muddy sediments make a good choice for them because it forms a better site for burrowing within the mud while sheltering themselves against predators. It also forms a better feeding ground as they can easily filter out food materials from the sediments, collect, scrap or shred food materials at the bottom of the water channel. The family is rare in stony of sandy stream beds because of the instability associated with such sediments which also exposes them to the risk of being easily washed away by currents and frequent predation.

Macroinvertebrates have also been collected and identified in high species numbers near tributaries of streams due to the availability of food while the lowest in impacted areas where there is pollution discharges and gravel excavation (Beqiraj, *et al* ., 2006).

Most of the macroinvertebrates collected and identified in Sasala Stream during this study belonged to the insect taxa (83%) while the non-insect taxa constituted only (17%)(Figure 4.10).This is probably because insects are taxonomically diverse and versatile in terms of their distribution and can occupy every water body so long as the physicochemical conditions are within the tolerable ranges. This further explains why aquatic insects are essential study organisms for comparing populations and community structures. Their assemblages provide reliable bio-indicators for investigating the effects of environmental disturbances because they are important components of the food chains and food webs (Hannah, *et al*.,2007)

Hemipterans constituted 35% of the insects followed by the order Ephemeroptera (22%) as shown in(Figure 4.11).This is probably because these collector taxa can take advantage of increased primary productivity in bio-films (Benstead, *et al.*, 2004).Other insect orders such as dipterans lack specialized attachment structures and mechanisms for holding on to sediments in strong currents(Makoba, *et al.*, 2008).Most of the non-insect taxa belonged to order Gastropoda (Figure 4.12).

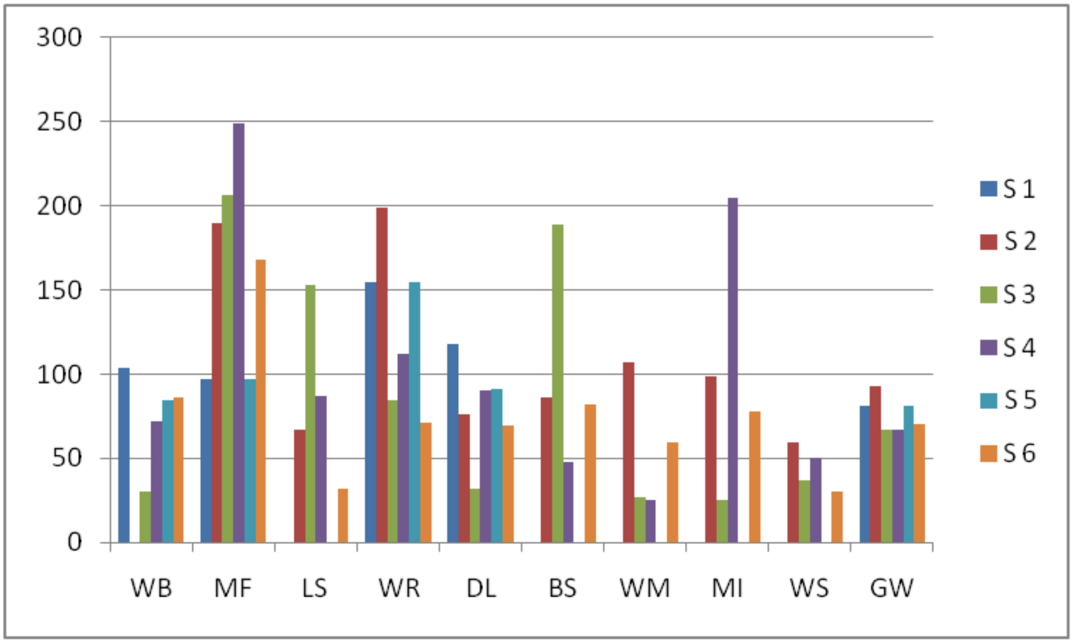

Figure 4.12: variations in macroinvertebrates families(numbers) within the study sites during the study period (March-August, 2016) WB=Whirligig beetles, MF=May flies, LS=Left spiral snails, WR=Water striders, DL=Dragon flies, BS=Back swimmer, WM=Water measurer, MI=Midges, GW=Giant water bug.

4.3.1 Variations in diversity indices

The Shannon-Weiner diversity index of the macroinvertebrates family was high in site Three (3) (H'=2.3), the catfish pond while the lowest was recorded in site one (1) (H'=1.585), the reference point upstream. (Table 4.4)

On the other hand, the Simpson diversity index was high in site six (D=8.065) the last sampling point downstream. The lowest was in site one upstream. (D=1.117). (Table 4.4).

Table 4.4: Mean (± SE) and Diversity indices Values of total numbers of families and individuals

Sampling sites	**1**	**2**	**3**	**4**	**5**	**6**
Means ±Se	56±19.6	98±18.8	85±22.5	101±22.7	51±18.1	75±12.03
Shannon- Weiner Diversity Index	1.585	2.192	2.359	2.101	1.575	2.196
Simpson Diversity Index	1.117	7.463	1.287	6.803	4.695	**8.065**

Source: Calculation from field data; figures in bold shows highest diversity indices.

4.3.2 Macroinvertebrates diversity and richness

There were variations in family diversity and richness of collected macroinvertebrates in the different sampling sites along the course of Sasala Stream. The upstream site (1) had the lowest mean followed by the last sampling site (6) downstream. The fish ponds (2and 3) and the fourth site (4) recorded the highest means of family diversity. High family diversity in the fish ponds may have been due to habitat type, water quality and availability of nutrients allowing complex interactions among the families in terms of competition and niche use. This agrees with Jones, *et al.*, (2002). Kibichi, *et al.*, (2007) reported that change of riparian land to agro-ecosystems in the River Njoro water shed led to changes in habitat quality resulting to decline in the diversity of benthic macroinvertebrates.

Higher taxon richness with lower diversity within the fish ponds (2 and 3) and site four(4) can be ascribed to poor habitat quality resulting from anthropogenic disturbances within the riparian zones that hasten erosion of sediments (which are actual or potential polluters) into the stream channel as reported by Death (2000).The diversity of macroinvertebrates is significantly influenced by the discharge of sediments in a water system. A related observation was made by Raburu, *et al*., (2009), where there was a universal decrease in taxon richness downstream as a result of increased human activities both in the river and riparian areas. In undisturbed or less disturbed sites, the intact riparian vegetation traps sediments, delaying transport of materials from the adjacent landscape and renders the stream banks more secure hence resistant to erosive activities (Carlisle, *et al.*,2003)

4.3.3 Composition and abundance of macroinvetebrates in the different sampling sites

The mean number of families and total number of individuals varied among the different sampling sites. (Table 4.4). The sampling site had a significant effect on the number of families (d.f=5; p=0.001) and number of individuals (d.f=5; p=0.001) collected.

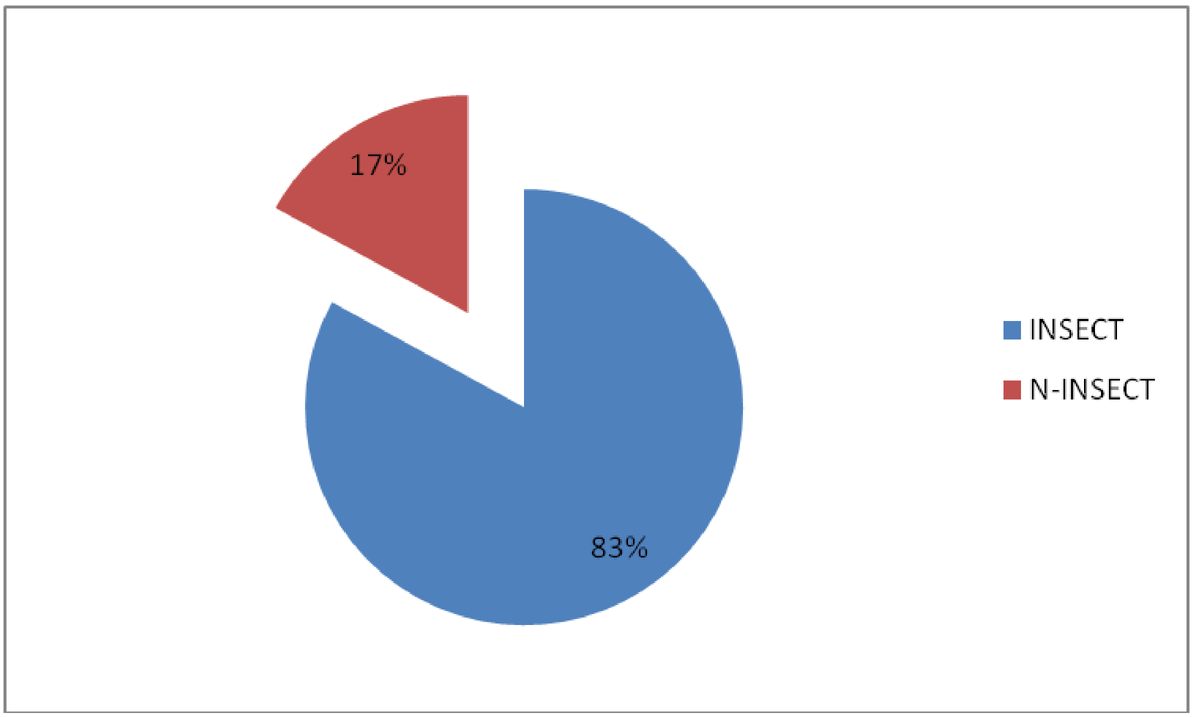

Figure 4.10: percentage composition of macroinvertebrates taxa collected from Sasala Stream during the study period (March to August 2016)

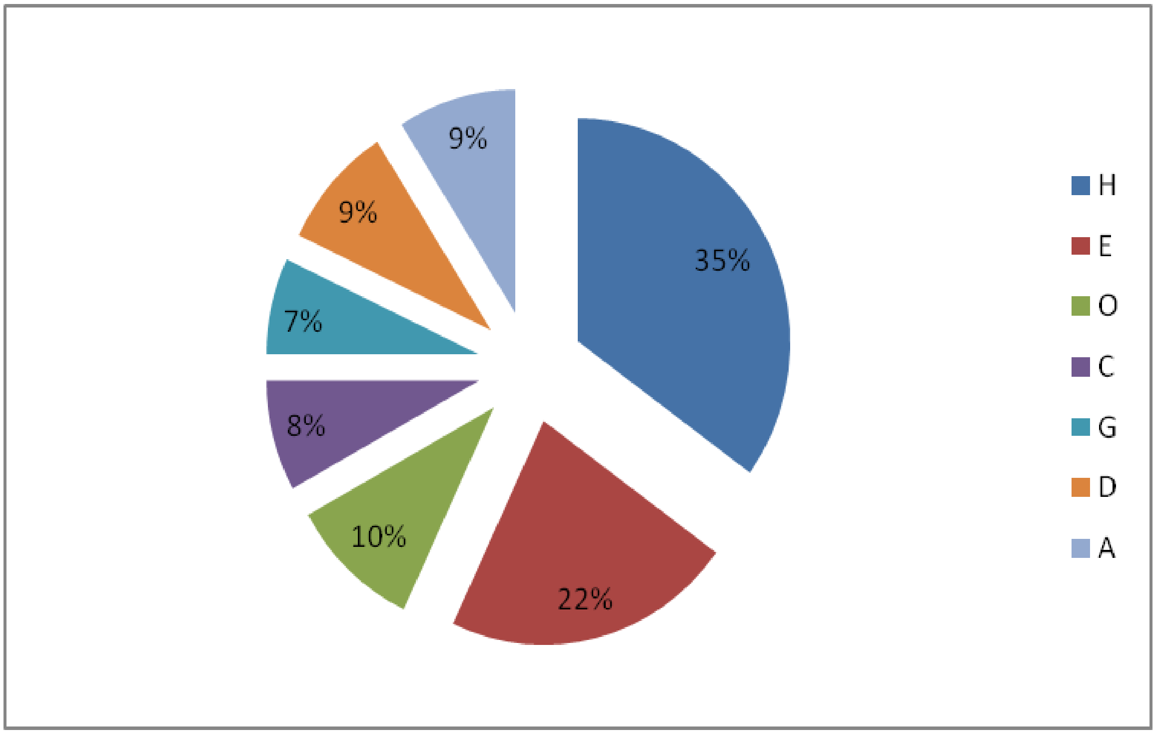

Figure 4.11: Percentage composition of macroinvertebrates orders collected in Sasala Stream during the study period (March to August2016): H=Hemiptera, E=Ephemeroptera, O=Odonata,C=Coleoptera, G=Gastropoda, D=Diptera, A=Arachnida

Table 4.5: Mean (± SE) values of total numbers of families and individuals in Sasala Stream in the different sampling sites during the study period (March-August, 2016). N=Number of samples.

		Sampling sites					
	N	1	2	3	4	5	6
No. of families	108	5	9	10	10	5	10
No. of Individuals	108	561	978	850	1005	508	745
Means±SE	108	56±19.6	98±18.8	85±22.5	101±22.7	51±18.1	75±12.03

Source: calculation from field data

The number of individual macroinvertebrates collected was higher in Catfish pond (Site 3) and site four (4) compared to the less disturbed sites upstream (1) and site six downstream (6). This might be explained by two key reasons. First, within these sections, the habitat characteristics are highly variable and unpredictable due to anthropogenic impacts and fish activities in the fish ponds. At site four (4) which was a confluence of two streams, watering of cattle and sand harvesting was evidenced.

Therefore, only a few generalists Baetidae, Veliidae that inhabit habitats opportunistically can flourish well in them. Secondly, disturbed sites have limited niches that can only allow survival of a few taxa. Similar findings were reported by Jones, *et al*., (2002) and Carlisle, *et al.*, (2003).

On the contrary, in serene sites within the upstream site and site six downstream, water is comparatively cleaner and of superior quality, resulting in numerous niches that can be exploited by diverse taxa which also enhances composite relations amongst organisms' present. This allows for inhabitation inside these sites by large numbers of diverse taxa but with low relative abundances. These sites can only hold specialists that are restricted to these non-degraded sites resulting in the low relative abundances as observed in Sasala Stream. This supports the findings of Dudgeon (1993) that most pollution-sensitive aquatic insects such as stoneflies, alderflies and caddisflies require cool temperatures and are restricted to creeks and cool waters with high concentration of dissolved oxygen. Ahearn, *et al*., (2005) also reported low diversity of Ephemeroptera Placoptera and Tracoptera (EPT) taxa in agricultural land uses and several taxa within forested sites. Therefore, there is spatial disparity in the diversity and distribution of aquatic macroinvertebrates in the different sampling sites along Sasala Stream water shed.

4.3.4 Relationship between physico-chemical variables and macroinvertebrates families

Table 4.6: Spearman rank order correlation coefficients between physicochemical parameters and macroinvertebrates families in Sasala Stream during the study period (March to August, 2016)

	pH	Temp	DO	BOD_5	Turbidity	EC	TDS	Ammonia-N	Phos-P
Belostomatidae	**0.272**	0.02	**0.129**	0.016	0.061	**-0.260**	**-0.200**	**-0.200**	-0.085
	0.020	0.897	0.278	0.892	0.610	0.028	0.093	0.093	0.479
Veliidae	0.085	**0.169**	**-0.377**	**-0.472**	**0.156**	0.027	**0.223**	**0.477**	**0.449**
	0.479	0.156	0.001	0.000	0.191	0.821	0.060	0.000	0.000
Notonectidae	0.090	**0.382**	**-0.257**	**-0.480**	**0.198**	-0.072	**0.249**	**0.453**	**0.408**
	0.452	0.001	0.030	0.000	0.096	0.547	0.035	0.000	0.000
Hydrometridae	-0.008	**0.130**	**-0.139**	**-0.341**	0.029	**0.114**	**0.219**	**0.290**	**0.394**
	0.948	0.277	0.245	0.004	0.812	0.340	0.065	0.014	0.001
Baetidae	**0.213**	**0.207**	**-0.431**	**-0.407**	**0.204**	-0.099	**0.309**	**0.364**	**0.426**
	0.637	0.081	0.000	0.000	0.086	0.406	0.008	0.000	0.000
Gomphidae	0.036	-0.064	**0.178**	**0.347**	**-0.255**	0.071	0.049	**-0.366**	**-0.176**
	0.764	0.593	0.000	0.000	0.031	0.554	0.682	0.000	0.139
Physidae	**0.123**	**0.226**	**-0.616**	**-0.564**	**0.328**	-0.045	**0.208**	**0.562**	**0.618**
	0.303	0.056	0.001	0.000	0.005	0.709	0.080	0.002	0.000
Chironomidae	0.050	0.060	**-0.252**	**-0.227**	0.030	0.019	0.196	**0.181**	**0.304**
	0.670	0.600	0.033	0.050	0.83	0.872	0.099	0.127	0.010
Gyrinidae	**-0.147**	**-0.208**	**0.373**	**0.704**	**-0.222**	0.013	**-0.218**	**-0.600**	**-0.512**
	0.216	0.080	0.000	0.000	0.061	0.914	0.066	0.000	0.000

Figures in bold shows significant correlations

Spearman rank order correlation analysis showed a number of considerable associations among physicochemical variables and macroinvertebrates families (Table 4.6). Belostomatidae showed significant correlations with turbidity, and BOD_5 ($p<0.05$ in each case). The family can tolerate stream sections rich in organic matter thus inside the fish ponds, Tilapia (Site 2) and Catfish (site 3) fish ponds.

Family Notonectidae, showed significant negative correlations with DO, EC, BOD_5 and TDS ($p<0.005$ in each case) This Hemipteran taxon is fairly susceptible to pollution and as a result may not survive in stream reaches with increased deposition of organic matter.

Members of this taxon are surface dwellers and hence choose calm water surfaces with mild currents from where they cannot be washed away easily.

The families Physidae, Chironomidae also showed negative correlation with some of the physicochemical conditions including $BOD_{5,}$ DO, TDS. A confirmation that this family is sensitive to pollution and occurred mainly in the ponds and downstream sites.

Baetidae showed weak negative correlation with BOD_5(r=-0.407, $p<0.05$), DO (r=-0.431; $p<0.05$), EC (r=-0.0992; $p<0.05$. This is because this taxon is sensitive but fairly tolerant to environmental ruin ensuing from pollution. A Key reason for this taxon appearing in most of the habitats within the sampling sites where aquaculture activities may have resulted in poor quality of water. Kibichi *et a*l. (2007) observed similar trends in River Njoro where Baetidae was found in cultivated, nutrient-rich and constantly disturbed parts of the upper River Njoro watershed.

Family Hydrometridae and Gyrinidae was negatively correlated with pH (r=-0.147; $p<0.05$), Temperature (-0.208; $p<0.05$), Turbidity (r=-0.222; $p<0.05$), signifying that this taxon is extremely susceptible and thus prefers non-degraded habitats with less pollution. High turbidity and TDS are associated with fish activity and feeding in the fish ponds while heavy down pours that wash away the materials on which these macroinvertebrates attach themselves in the streams. This additionally explains why members of this taxon were restricted in sections of the stream where water is moderately fresh. The increased turbidity due to huge amounts of floating solids and other materials reduces light access. Suspended solids can obstruct respiratory surfaces or hinder the feeding appendages of the macroinvertebrates making filter feeders use extra energy, reducing their dietary value.

Suspended solids may settle at the floor altering the structure of the stream interfering with movement, feeding and reproduction of benthic forms. This leads to lowered abundance of the tolerant taxa during rainy season when turbidity is high. This agrees with Kibichi, *et al.,* (2007) and Shivoga, *et al.,* (2001) who observed that in River Njoro Basin, the majority of the very susceptible macroinvertebrates taxa (Ephemeroptera, Trichoptera and Plecoptera) are limited to unpolluted sections.

However, the positive correlation between Belostomatidae and turbidity ($r=0.06$; $p<0.05$), pH ($r=0.0.27$; $p<0.05$) and BOD_5 ($r=0.0.01$; $p<0.05$) was because of the tolerant nature of this taxon. This illustrates why the taxon was common in site 2(Tilapia fish pond) and site 3(Cat fish pond).

However, Physidae were correlated positively with temperature, ammonia and turbidity. These taxa were characteristic of less disturbed sites-upstream and site six. This concurs with Lewis, *et al.,* (1995) who reported that macroinvertebrates taxa indices were determined by nutrients concentrations and that biotic integrity of low to mid order streams is negatively correlated with nutrients. This is because streams with intact riparian buffers are expected to have lower levels of phosphates than those with degraded riparian vegetation.

Family Gomphidae, showed major positive correlation with TDS, Dissolved oxygen and pH signifying that this taxon is fairly tolerant to habitat dilapidation. Adult forms are swift fliers and can move to stream sections where the quality of the habitat is within acceptable limits.

Physidae, positively correlated with temperature ($r=0.22$; $p<0.0056$), TDS($r=0.208$; $p<0.080$), pH($r=0.123$; $p>0.303$), Phosphate-Phosporus ($r=0.618$; $p<0.05$),Turbidity($r=0.328$; $p<0.05$) and Ammonia($r=0.582$;$p<0.05$).This indicates that this taxon is very tolerant to pollution and this explains why it was observed more commonly in the fish ponds.

It is consequently, observed that amongst the bottom dwelling macroinvertebrates, nutrients are essential in shaping their distribution because of the strong connection between nutrients and organic matter. The majority of macroinvertebrates can thus bear organic pollution that is also a source of their food

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the findings of this study, the following conclusions can be made:

- There are spatial variations in physicochemical variables from the upstream to downstream of Sasala Stream watershed, equivalent with changes caused by discharge from fish ponds.
- Within the watershed, the upstream site (Site 1) and downstream site (Site 6) showed lower values of pH, Temperature, BOD_5, TDS, Electrical conductivity, Ammonia-nitrogen, Turbidity and Phosphate-Phosphorus and higher values of Dissolved Oxygen.
- Additionally, there was higher abundance of tolerant taxa in the fish ponds and some downstream sites (4).
- The results of this study suggest that the major physico-chemical parameters (e.g. BOD_5, EC, TDS, turbidity, Phosphate-Phosphorus, ammonia-nitrogen) in Sasala Stream were influenced by the discharge from the fish ponds.
- Some of the tolerant taxa Chironomidae were found.
- It is evident that macroinvertebrates can be used to monitor quality of streams receiving discharge from fish ponds.
- Riparian width is important not only for the reduction of soil erosion by increasing bank stability and input coarse organic matter, but also for the decrease of water temperature through shading in the stream habitat.

- BOD_5 results indicate that the upstream and the furthest site downstream has water of good quality as compared to the water in the fish ponds and the immediate points immediately after the fish ponds.
- There was spatial variation in macroinvertebrates diversity, richness and distribution within the stream watershed resulting from fish pond discharge.
- The fish pond sites (2 and 3) and site four (4) had higher macroinvertebrates family diversity as compared to the upstream and downstream locations.
- The intolerant families occurred at sites outside the fish ponds. Baetidae (tolerant to pollution) an Ephemeropteran family occurred in large numbers in the fish ponds.
- The relationship between the physicochemical conditions and macroinvertebrates assemblages of Sasala Stream, confirm that macroinvertebrates are affected by physicochemical state of water.
- That macroinvertebrates can be used in stream water quality monitoring and investigating aquaculture impacts on aquatic ecosystems.
- Therefore, nutrients particularly Ammonia and Phosphate –Phosphorus are important in determining the distribution of aquatic macroinvertebrates because of the strong association between these nutrients and organic matter.
- For aquaculture to be sustainable, production systems must focus on the interactions between the culture techniques and the environment.
- It is important to note that the growth and the expansion of aquaculture as an industry is occurring during a period of growing concern of its environmental implications.

- As a result, the sustainability of aquaculture practices has come into increasing scrutiny for social equity, ecological integrity and long-term economic viability.
- The social implications generally becomes evident from the very early stages of farm development, but the ecological impacts may take a much longer time to unravel and the reducing effects may be monumental.
- Against this background, it is widely accepted that aquaculture requires a framework of regulations to ensure sustainability and minimize potential environmental impacts.
- Good management is therefore essential so that any aquaculture activities fit in a sustained manner within the environmental policies that will enhance harmonious operations of aquaculture practices in a particular locality.
- In this regard regulations must conform to national policy and international standards including those outlined by the Kenya National Environment Management Authority (NEMA), Water Resources Management Authority (WRMA), Kenya Bureau of Standards (KEBS). Kenya Fisheries Service (KFS) as well as other related Agencies of Government.
- The Agencies have powers on matters relating to environmental, water and natural resources protection.
- It is on record that effluent limitations for non-point and point sources have been established, for the practices of environmentally friendly aquaculture which will ultimately lead to sustainable fish farming with no negative impact on the environment.

5.2 Recommendations

From the findings obtained of this study, the following recommendations can be made:

- ❖ More studies are required to confirm the observed spatial trends in the physicochemical conditions and macroinvertebrates taxa diversity and distribution within Sasala Stream watershed.
- ❖ Temporal and spatial studies on long term basis, covering both rainy and dry seasons, are recommended to confirm this.
- ❖ There is need for more studies on the different tributaries in the lower reaches of Sasala Stream in order to understand their ecological status and possible impacts of aquaculture effluents based on culture method and species cultured.
- ❖ There is need to collect representative taxa including the rare ones from the stream and rear them within a simulated laboratory environment to determine their exact responses to changes in water quality under controlled situations.
- ❖ This can further allow for more studies on the physiology and anatomy of these macroinvertebrates taxa under controlled environment in relation to reproduction, feeding mechanisms and responses to aquaculture effluent changes and stressors.
- ❖ There is also need for studies to confirm possible predation on the macroinvertebrates by fish as a source of food.
- ❖ There is need for the government both national and county to review existing legislation on establishment of aquaculture ventures to incorporate measures that ensure sustainable fish farming.

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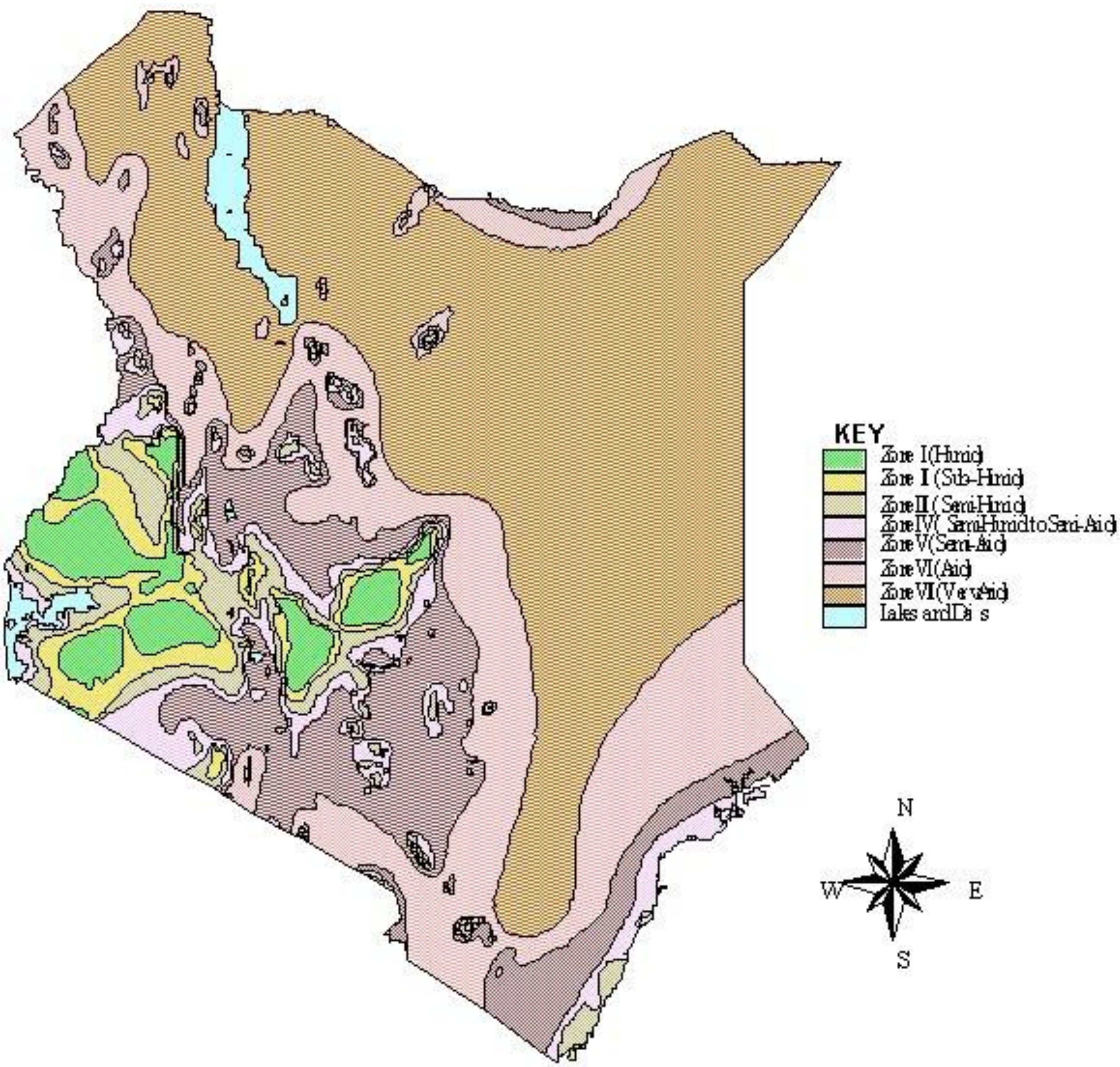
APPENDICES

Appendix I: Map of agro-ecological zones and potential for aquaculture in Kenya



Source: Ngugi and Manyala, (2009)

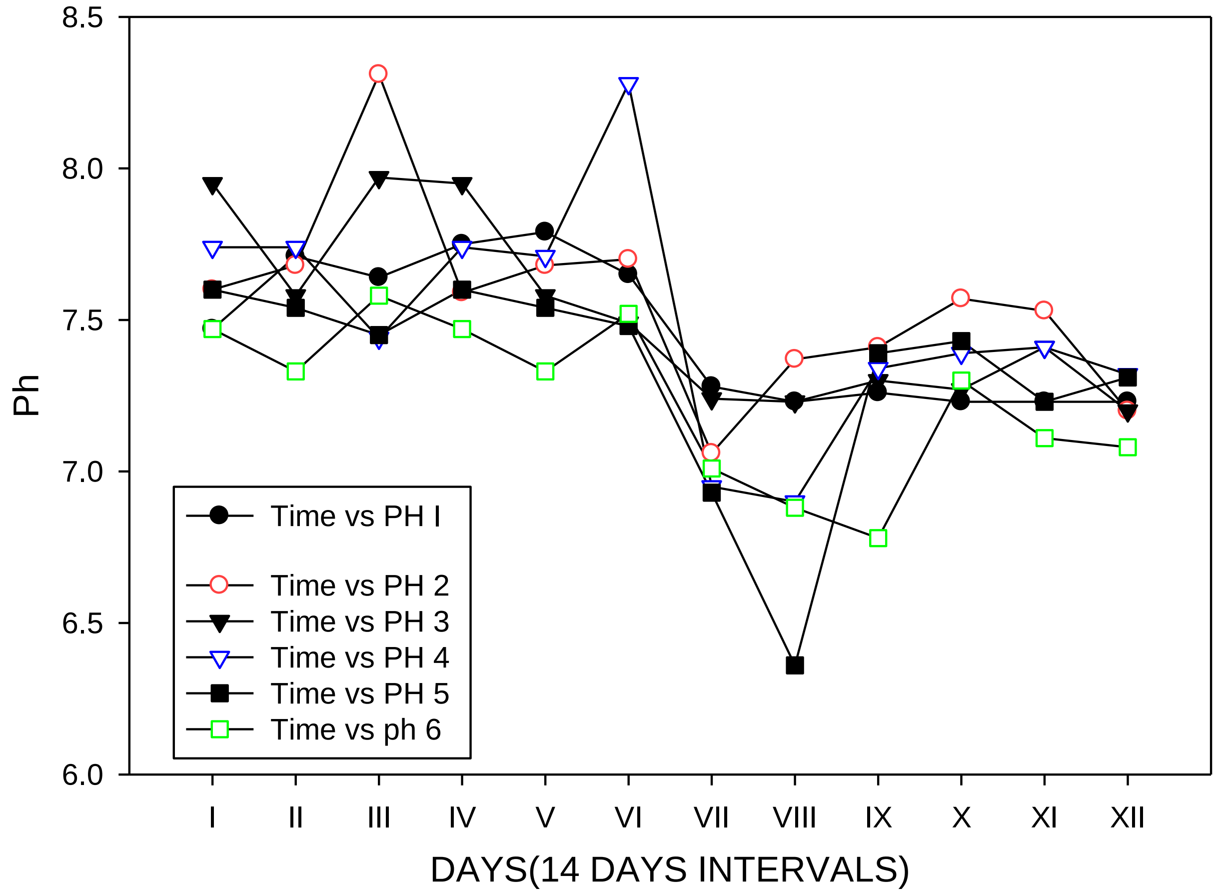
Appendix II: Coordinate information of sampling points/sites

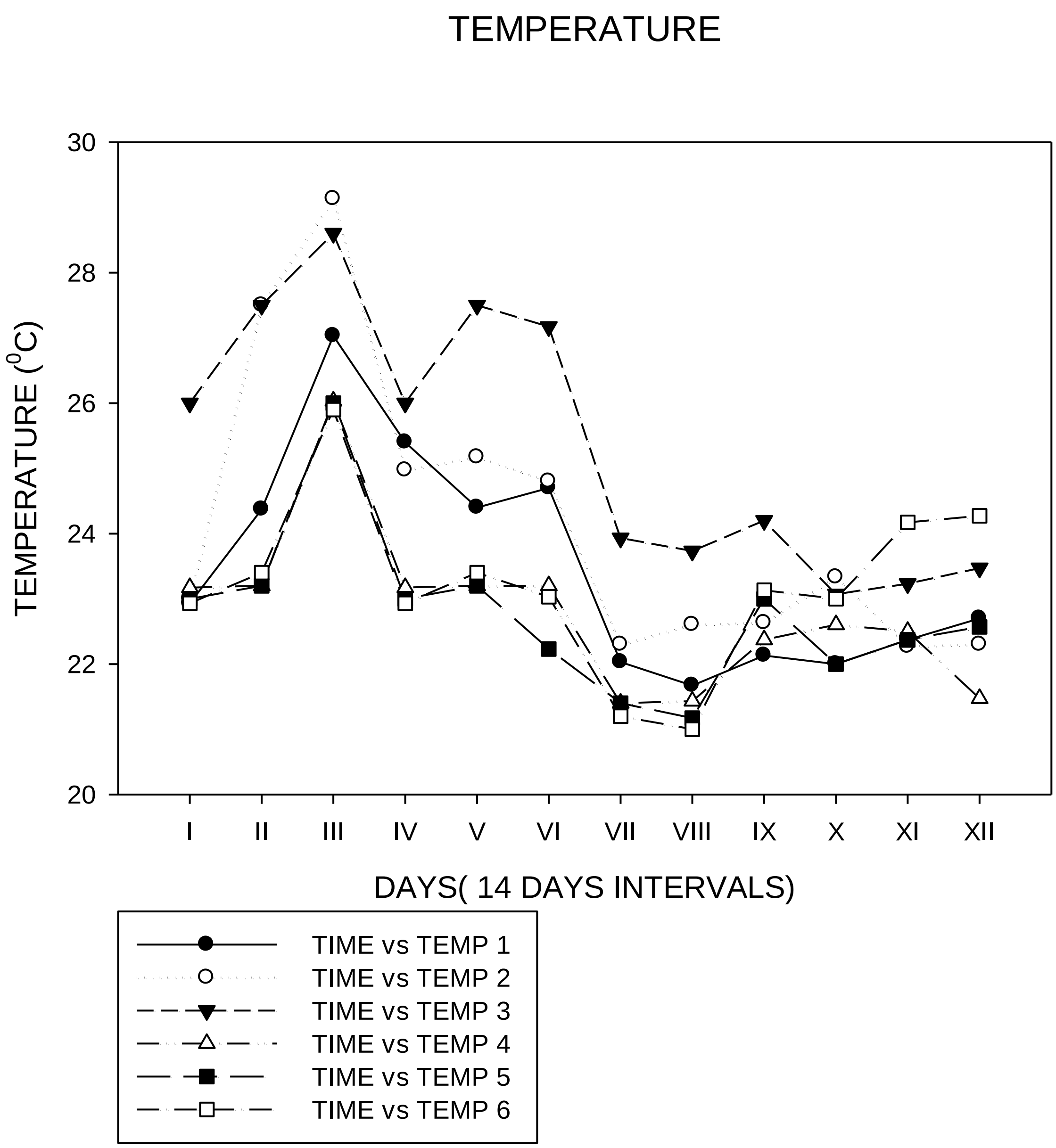
S/N	NAME	NORTHINGS	EASTINGS	ELEVATION
1	S1	0.279417222	34.6827075	1405.41
2	P1	0.279909167	34.682345	1402.49
3	P2	0.281341667	34.68149417	1380.2
4	P3	0.281431389	34.68138889	1385.91
5	S2	0.280753611	34.68081778	1400.15
6	C1	0.282107778	34.68126389	1397.3
7	P4	0.282107778	34.68120389	1392.55
8	P5	0.282233889	34.68128889	1373.72
9	S3	0.281814722	34.68270444	1393.47
10	C2	0.282429722	34.68097972	1380.84
11	H1	0.282456667	34.68092222	1381.24
12	P6	0.282238889	34.68008975	1377.4
13	P7	0.28275	34.68080889	1376
14	P8	0.283	34.68078028	1380
15	P9	0.283167222	34.68078028	1370
16	P10	0.2832875	34.68080556	1382.64
17	P11	0.283552222	34.68074444	1374.33
18	P12	0.283726389	34.68071389	1372.31
19	P13	0.283919444	34.68073056	1373.7
20	P14	0.284242778	34.68069583	1374.93
21	C3	0.284393056	34.68066806	1370.7
22	P15	0.284005556	34.68052778	1372.8
23	P16	0.284005556	34.68031778	1369.15
24	P17	0.284097778	34.68024167	1373.14
25	P18	0.283642222	34.680075	1374.13
26	S4	0.282991667	34.67910694	1368.34
27	E1	0.284474444	34.68086167	1374.39
28	E2	0.284650556	34.68107972	1365.81
29	E3	0.285100278	34.68135028	1367

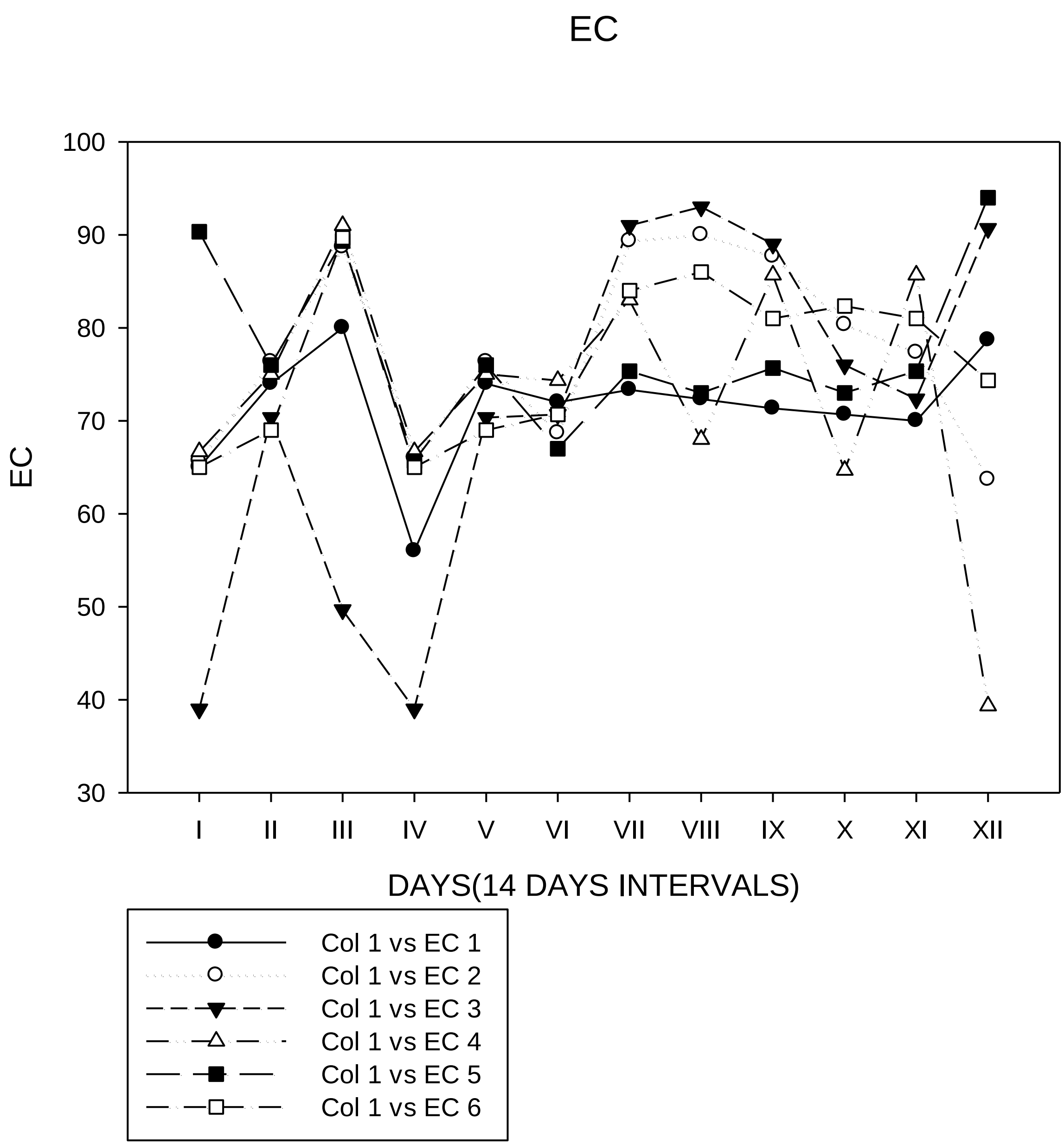
Source: Field Data 2014

Appendix III: Summary of Physicochemical parameters during the study period

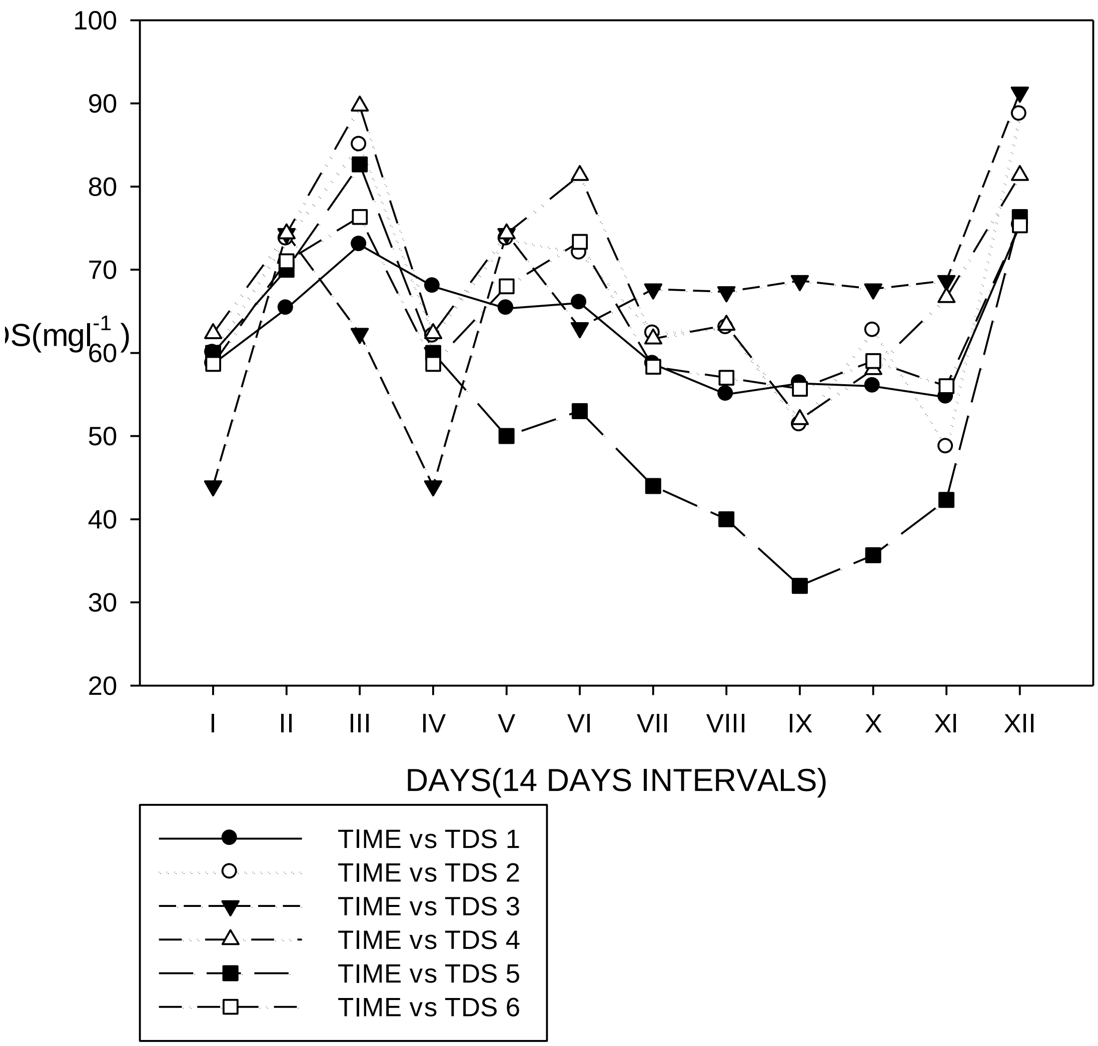
pH



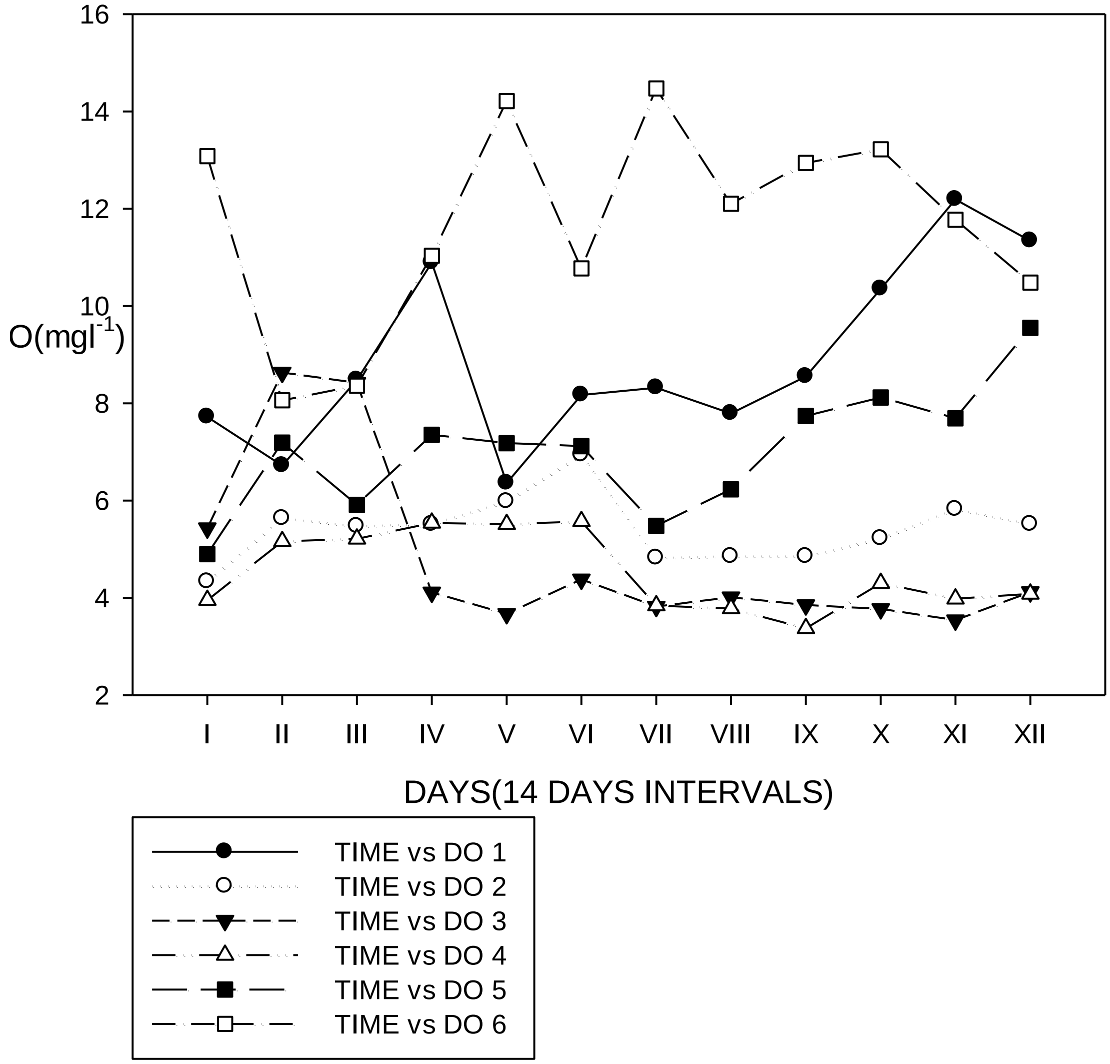

TEMPERATURE
30
28
26
24
22
20
TEMPERATURE (^{0}C)
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
DAYS(14 DAYS INTERVALS)
TIME vs TEMP 1
TIME vs TEMP 2
TIME vs TEMP 3
TIME vs TEMP 4
TIME vs TEMP 5
TIME vs TEMP 6


EC
100
90
80
70
60
50
40
30
EC
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
DAYS(14 DAYS INTERVALS)
Col 1 vs EC 1
Col 1 vs EC 2
Col 1 vs EC 3
Col 1 vs EC 4
Col 1 vs EC 5
Col 1 vs EC 6

TDS

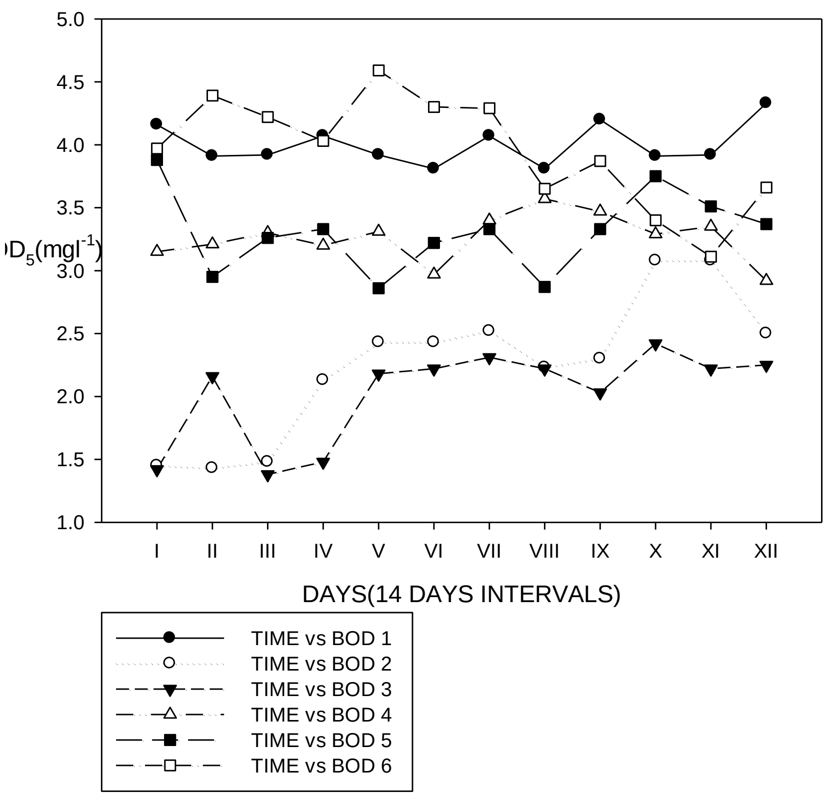

100
90
80
70
60
50
40
30
20
DS(mgl-1)
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
DAYS(14 DAYS INTERVALS)
TIME vs TDS 1
TIME vs TDS 2
TIME vs TDS 3
TIME vs TDS 4
TIME vs TDS 5
TIME vs TDS 6

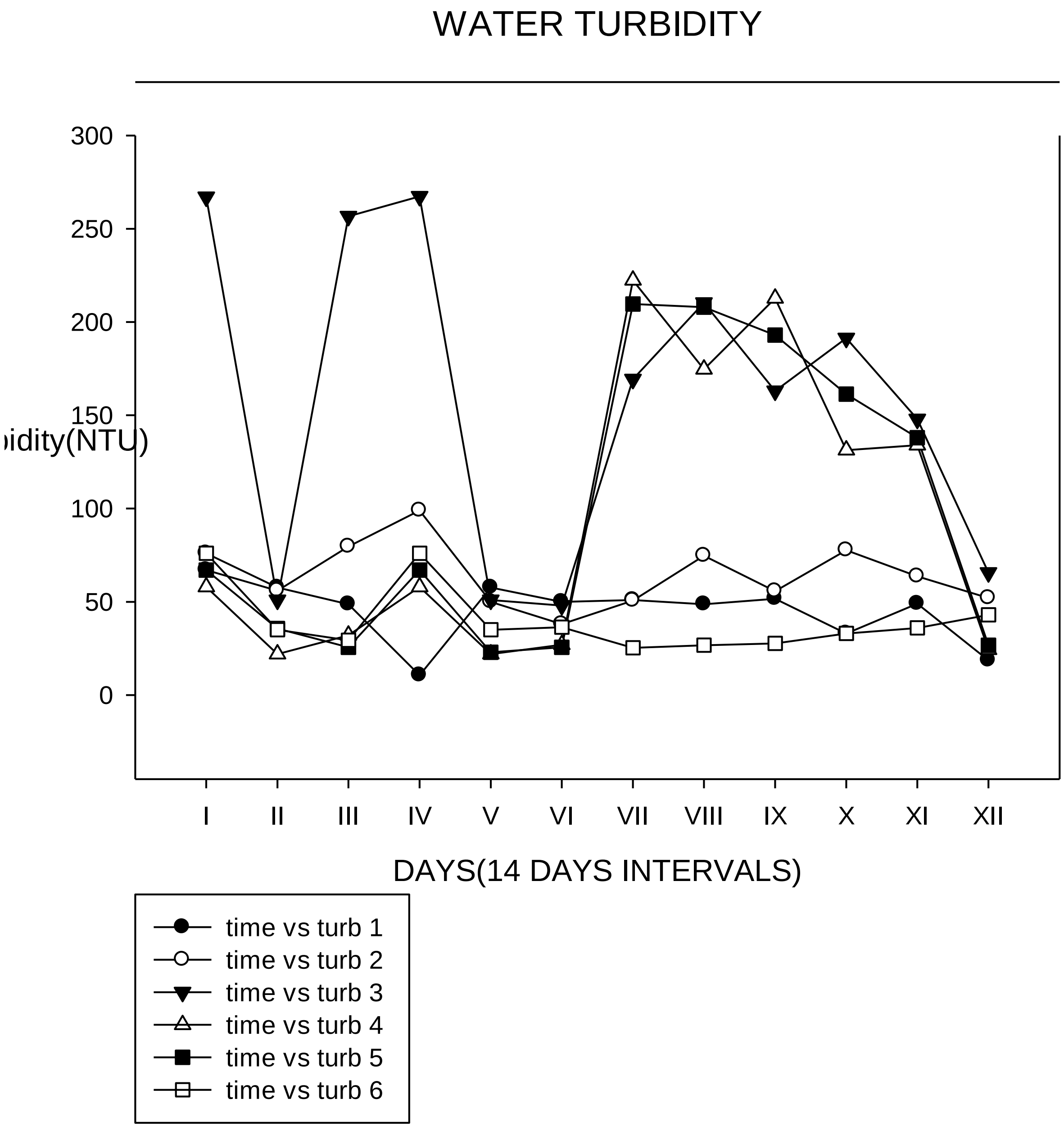
DO



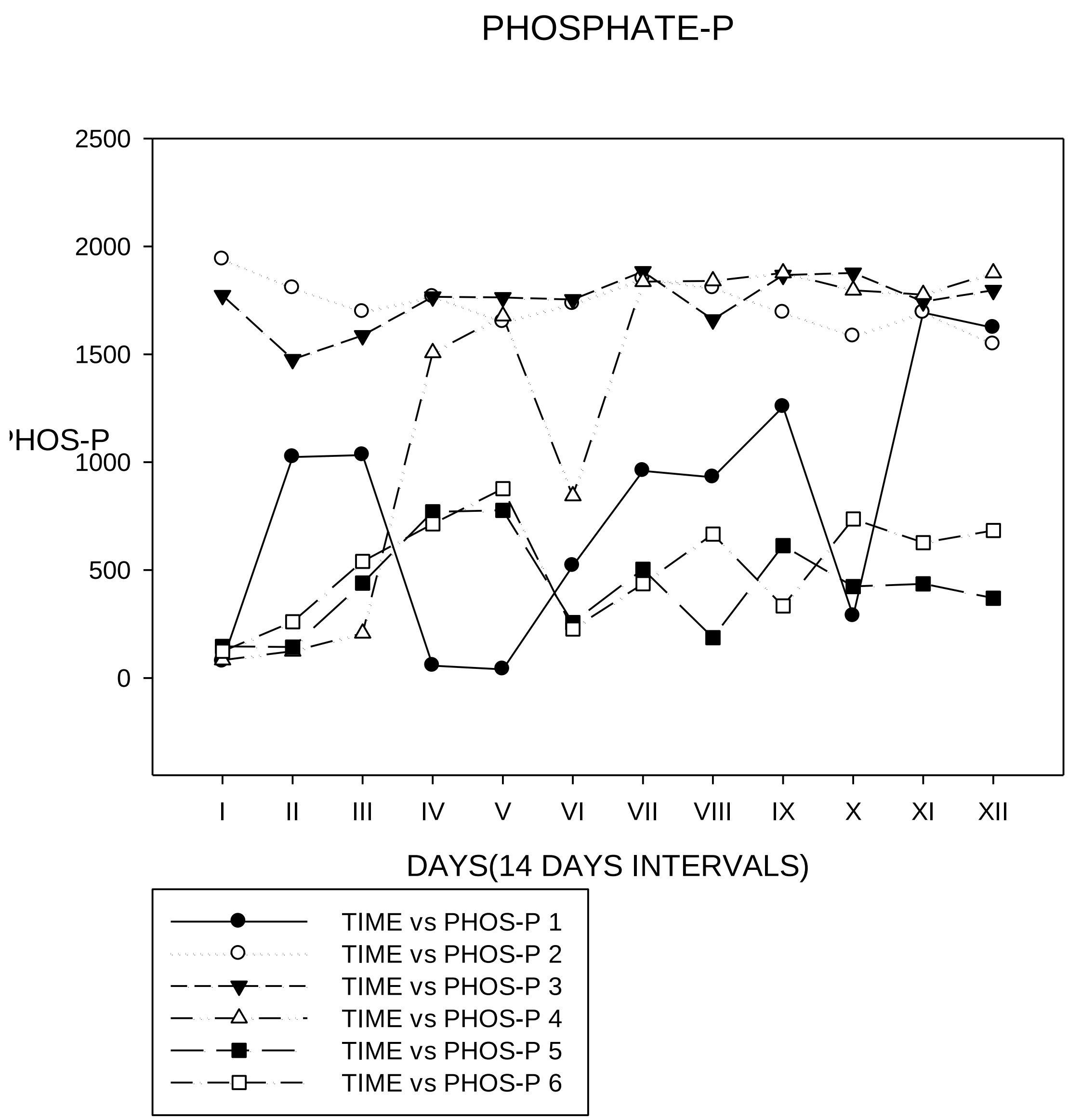
16
14
12
10
8
6
4
2
O(mgl-1)
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
DAYS(14 DAYS INTERVALS)
TIME vs DO 1
TIME vs DO 2
TIME vs DO 3
TIME vs DO 4
TIME vs DO 5
TIME vs DO 6

BOD

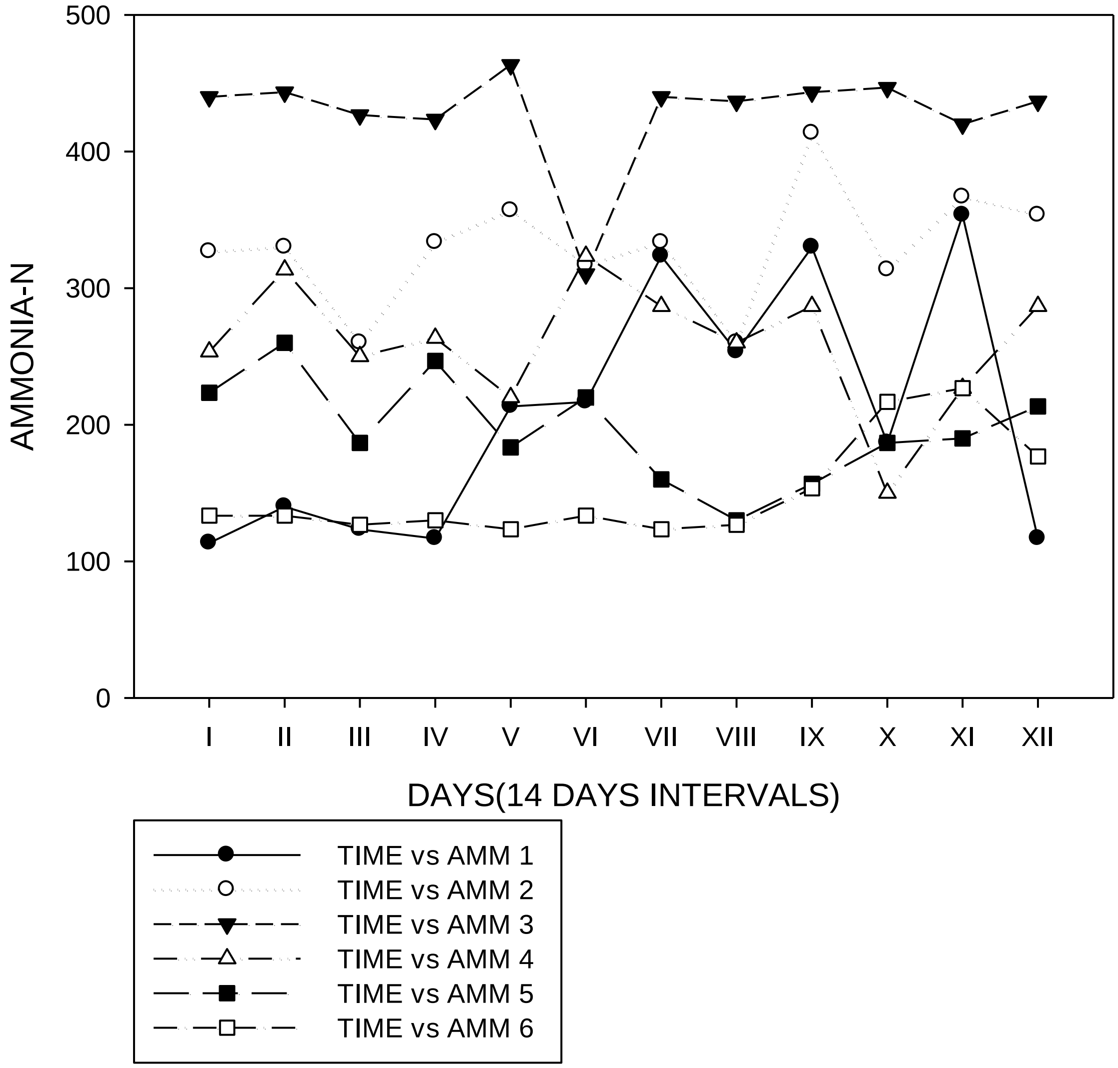

D5(mgl-1)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
DAYS(14 DAYS INTERVALS)
TIME vs BOD 1
TIME vs BOD 2
TIME vs BOD 3
TIME vs BOD 4
TIME vs BOD 5
TIME vs BOD 6



WATER TURBIDITY
300
250
200
150
100
50
0
idity(NTU)
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
DAYS(14 DAYS INTERVALS)
time vs turb 1
time vs turb 2
time vs turb 3
time vs turb 4
time vs turb 5
time vs turb 6


PHOSPHATE-P
PHOS-P
2500
2000
1500
1000
500
0
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
DAYS(14 DAYS INTERVALS)
TIME vs PHOS-P 1
TIME vs PHOS-P 2
TIME vs PHOS-P 3
TIME vs PHOS-P 4
TIME vs PHOS-P 5
TIME vs PHOS-P 6

AMMONIA



AMMONIA-N
500
400
300
200
100
0
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
DAYS(14 DAYS INTERVALS)
TIME vs AMM 1
TIME vs AMM 2
TIME vs AMM 3
TIME vs AMM 4
TIME vs AMM 5
TIME vs AMM 6