INTEGRATED ASSESSMENT OF THE HEALTH OF RIVER SOSIANI; KENYA

BY

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A Thesis Submitted to the School of Graduate Studies in Partial Fulfilment of the Requirements for the Award of the Degree of Master of Science in Fisheries and Aquatic Sciences (Aquatic Sciences Option) University of Eldoret.

2013

DECLARATIONS

Declaration by the candidate

This thesis is my original work and has not been presented to any other university for the award of a degree. This work should not be reproduced without the express authority of the author and/ or University of Eldoret.

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DEDICATION

I am obliged to dedicate this thesis to the source of all intelligence, discernment, insight, knowledge and understanding; to the only wise God, for his sufficient grace and strength to enable me to learn of his creation. In addition, to my parents, who have ever motivated me to face life despite the complexity and contrary in it, in the philosophical and experiential view, pointing me to good morals, to achievement in life and to perfection. The dualistic nature of life challenges, yet teaching me to be biased and inclined to the optimism perspective. To Meshack and Dolphine Achieng', thank you for the investment you bestowed in me.

To my brothers Jared and Gilbert, who will tell me to my face that "***I'm proud of you***", and to my sisters Celestine, Millicent, Irene and Caroline, who always hoped for the best from my daily activities; the encouragement, comfort and assurance of your care. Thank you all for the confidence you have ever had in me. My heart felt gratitude goes to my friends, who are brothers to me too. The value you have had for my life, the investment you did in it and the careful and tactical planning for its future evident in the seed planted in this Master degree credit. To Aliahmed Hassanali, Aazam Virani, Jiten Patel and Mohammad Umer Salloo.

Last but not least, to Reverent Reuben Kigame for expanding my philosophical thinking gaps, giving me a challenge to read wide in all the areas of my interest in life, my yean for knowledge is partly due to your invoking. Thank you all for shaping my life and may God richly reward you.

ABSTRACT

This study set out to evaluate the effect of anthropogenic activities by analyzing the physical habitat characteristics, physico-chemical water quality parameters, macrophytes and macroinvertebrates as indicators of water quality degradation and to develop an integrated index to assess the health of River Sosiani from August 2012 to February 2013. Physical habitat characteristics were observed and measured by a tape measure and a GPS. Physico-chemical water quality parameters were temperature, pH, TDS and Conductivity measured *in situ* while TP, TON, BOD and DO were measured *in vitro* using standard methods. Protocols for identification of biological communities were used for macrophytes and macroinvertebrates. Physical habitat characteristics were more of destructive practices on the riparian zone of the river ecosystem. Physico-chemical water quality parameters' measurement were high during dry season than wet season, except for DO which was high in wet season. However, there was strong correlation of these parameters with the stations in both seasons except for pH (r = -0.017 and p = 0.948). Huruma and Maili inne stations were distantly related to the other stations in both seasons. Principal component analysis with component 1 explaining 60.5% variance and component 2 explaining 26.1% variance evaluated TON and TP as key pollutants in both wet and dry season, with BOD levels high at Huruma and Maili inne. Varifactor 2 that explained 35.3 % of the variance in wet season and 27.1% in the dry season had a strong negative factor loading of BOD (Wet; -0.878, Dry; -0.915) and also of TP (Wet; -0.839, Dry; -0.709) in both seasons. Varifactor 3 that explained 18.4% variance in wet season and 21.7 % in the dry season also had a strong negative factor loading of TON (Wet; -0.822, Dry; - 0.861) in both seasons. Macrophytes' abundance with TON and TP gradient was high at stations where concentration of the nutrients was also high. Macroinvertebrates' response of 25 families had a tolerance level to TP of 0.1 mg/l, 15 families had the same tolerance level to TON and similarly, 11 families to BOD. Habitat Index, Macrophyte and Macroinvertebrate Index were reliable in assessment of River Sosiani. Integrated Index for River Sosiani Health evaluated it in the range moderate to poor quality class. The study recommends for appropriate environmental management measures, continuous monitoring and awareness creation for all stakeholders. The index can be used to evaluate the health of rivers in the upper catchments of Lake Victoria Basin and other high altitude streams in Kenya.

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LIST OF ABBREVIATIONS AND ACRONYMS

APHA	American Public Health Association
ASPT	Average Score per Taxon
BACI	Before and After with Control
Bf and Aft	Before and After
BIRSH	Biotic Index for River Sosiani Health
BMWP	Biological Monitoring Working Party
CBI	Chandler Biotic Index
D/Dmax	Dominance and Maximum Dominance
EPA	Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera and Trichoptera
EU-WFD	European Water Framework Directive
FA	Factor Analysis
Ff	Free floating
GPS	Global Position System
HI	Habitat index
HIRS	Habitat Index for River Sosiani
IIRSH	Integrated index for River Sosiani Health
KPLC	Kenya Power and Lighting Company
NPM	Nutrient Pollution Metric
PCA	Principal Component Analysis
PHABSIM	Physical Health Assessment Basin Simulation
PMRS	Pollution Metric for River Sosiani
QC	Quality Class
RR	Riverine
S/Smax	Richness and Maximum Richness

SA	Semi Aquatic
TBI	Trent Biotic Index
UNEP	United Nation Environmental Protection
UNESCO	United Nation Education Social and Cultural Organization
VIBI	Vegetation Index of Biotic Integrity
WHO	World Health Organization

ACKNOWLEDGEMENT

My sincere gratitude and homage is explicitly at the onset, first, to my immediate supervisor Dr. Phillip Raburu. With all regard and due respect, this work has materialized almost entirely due to your support, whether directly or indirectly. It can hardly ignore your contribution and profession in its sounding results to its conclusion. The financing, adjudication and advice through reading materials, formulation and developing of the objectives that enabled my focusing on key issues in the research problem to its results and interpretation, the patience you have had; all through my fumbling to the current stand. My humble respect and honor also goes to Prof. Emmanuel Kipkorir for the co-supervision of my research work all through to its completion. Your contribution in advice and instruction that channeled my perspective to bring out this results. Thank you for the contribution that you made in my life.

Many thanks also goes to Mr. Bernard Wanjohi, Mr. Henry Lubanga and Mr. David Namwaya for your assistance during my field work and sampling period, to my close friends, Aliahmed Hassanali, Aazam Virani, Jiten Patel and Umer Salloo for the financial support. Thank you all for the value you have put in me.

CHAPTER ONE

INTRODUCTION

1.1. Background

The concept of bio-assessment of aquatic ecosystem begun with Kolkwitz and Marsson (1908, 1909). They exploited the effect of point source pollution from sewage discharges on aquatic fauna and flora downstream of urbanized areas, and presented a practical system for water quality assessment using biota. This was known as Saprobic system, and was based on the observation that a change in biota occurs downstream of major source of organic matter pollution (UNESCO/WHO/UNEP, 1996). Alternative approaches to the Saprobic Index were developed by Cairns *et al*. (1968), Woodiwiss (1964) Trent Biotic Index (TBI), Chandler (1970) Chandler Biotic Index (CBI) and others, based on the presence or absence of certain indicator species, at the sampling point. Family level identification (Hellawell, 1986; Abel, 1989) indices were latter developed in order to limit the taxonomic requirement of earlier biotic indices that identified organisms to species level such as the Biological Monitoring Working Party (BMWP) and Average Score per Taxon (ASPT) (UNESCO/WHO/UNEP, 1996).

However, recent biological assessment methods are based either directly or indirectly, on the concept of comparison of natural conditions of biotic structure, species composition, function and diversity (Davies and Jackson, 2006; Stoddard *et al*., 2006). The indicative quality of bio-indicators ranging from organelles, organs or single organisms to complex ecosystems. Depending on inherent eco-physiological properties, population dynamics, and stress reactions with regard to physical and chemical changes in site conditions (Stoddard *et al*., 2006). Moreover, the primary task of bio-indicators being the general determination of physiological effects in the sense of strain reactions rather than the direct measurement of environmental concentrations of stressors (Franzle, 2006).

A 'healthy' river is one that has retained its biodiversity and ecosystem integrity (Bond *et al.,* 2012). Philosophically, the term river health is readily interpreted by the public and evokes societal concern about human impacts on rivers (Boulton, 1999; Norris and Hawkins, 2000). The health of a river depends on its ability to maintain its structure and function; to recover after disturbance; to support local biota and to maintain key processes like sediment transport, nutrient cycling and energy exchange (Bond *et al.,* 2012). The difficulty in river health assessment however arises in the choice of relevant symptoms yet, there is a wide variety of indicator parameters that can be measured with varying accuracy at a broad range of spatial scales (Norris and Thoms, 1999). These indicators may respond to impacts at different time scales, and no single indicator can reveal river health unequivocally (Boulton, 1999).

The past decades have seen a proliferation of assessment methods designed to describe and evaluate stream characteristics (Verdonschot, 2000; Roper *et al.,* 2002; Skoulikidis *et al.,* 2004). Verdonschort (2000) summarizes them into eight major groups of assessment techniques; indices (saprobic, diversity, biotic), multi-metrics and rapid techniques, physico-ecological, catchment scale, ecosystem components, assemblage/community, process and non-taxonomic assessment.

Since a riverine ecosystem is essentially a spatial and temporal dynamic entity determined by the interaction of the structural features of the channel and the hydrological regime (Maddock, 1999), it has different micro/macro-habitats along the channel. In a stream channel where sampling sites are not physically comparable, habitat characterization is important for proper interpretation of assessment results (Roux *et al.*, 1993). Having knowledge of the habitat, besides human influence, is therefore fundamental to local habitat assessment. It is widely agreed that large-scale catchment features (Boulton, 1999; Bunn *et al*., 1999) influence stream habitats. Broad-scale assessment of stream health is therefore often based on correlative relationships between catchment land-use categories and measurements of stream biota or water chemistry (Clapcott *et al.*, 2010).

Today, the biological, physic-chemical and hydro-morphological characteristics of a large number of rivers have deteriorated (Boon, 1992; Kristensen and Hansen, 1994; Petts, 1990; Verdonschot, 2000; Skoulikidis *et al.*, 2004). These three components are vital in characterizing water bodies (UNESCO/WHO/UNEP, 1996), and have therefore been widely used in monitoring and assessment either as a unit, or in integration as the indicators, or to develop indicators that can assess the quality of an aquatic ecosystem.

A wide range of physic-chemical, biological and hydro morphological variables have been used in river health assessment, and reliable results in modified assessment methods using these parameters/components have been practiced in Kenya. For instance, the modified Index of Biotic Integrity and Nyando Habitat Evaluation Index applied along the River Nyando (Raburu, 2003), Assessment of pollution impacts on the ecological integrity of the Kisian and Kisat rivers in Lake Victoria drainage basin (Kobingi *et al.,* 2009) and, Macroinvertebrates' community structure in Rivers Kipkaren and Sosiani, River Nzoia basin (Aura *et al.*, 2011) among others.

Most of these modified assessment methods in Kenya have integrated fewer biotic indices and water quality parameters to assess stream health. More so, the common goal of stream heath philosophy is still a challenge worldwide. The practical activities being challenged by the complexity in river systems and fundamentally limited knowledge: sampling being faced with strong choice biasness with assumptions about the nature and value of ecosystem processes that underestimate its complexity and uncertainty (Harris and Healthweit, 2012). Data analysis and interpretation based on assuming reliability of measurements and their response time at range of scale to validate the assessment indicator. In such an environment, exploration by integration of the measurements and linking them with impaired stream ecology; appropriate choice of indicator and rigorous sampling and analysis, and careful data interpretation—matched with effective communication—is necessary for the achievement of river health assessment (Boulton, 1999).

Since no single indicator alone is best, and a synthetic approach that adopts a group of relevant metrics may prove most effective at measuring river health (Boulton, 1999), assessment of river health requires integration of the components that characterize water bodies (Norris and Hawkins, 2000; Meng *et al.,* 2009; Nick *et al.*, 2012). This study therefore aimed to develop and integrate indices for assessment of the Health of River Sosian. It evaluates the physical habitat, physic-chemical water quality parameters and the response of Macrophytes and Macroinvertebrate communities. It further evaluated the reliability of indices developed in assessment of River Sosiani compared to the documented studies on stream health assessment—as the first in Sosiani River's Health Assessment.

1.2. Problem Statement

Anthropogenic pollutants including domestic sources, urbanization, agricultural activities, industrial activities, mining and quarrying activities, and physical alteration of habitats, have been identified as significant threats (UNEP, 2000; Theodoropoulos and Iliopoulou-Georgudaki, 2010; Torrisi *et al*., 2010) to rivers' health over the past decades (Meng *et al.*, 2009; Benini *et al.*, 2010). Sosiani River in Uasin Gishu County is not exempt. Along the river are several anthropogenic activities including human settlement scheme, railway station, Kengen Sosiani hydropower generation station, land use such as agriculture including cattle ranching and flower farming, impoundments at Elegrin and Two Rivers Dam, increased human settlements and institutions that discharge their waste in the river, Kaptinga quarry and boundary sewerage plant (Otieno, 2010). The disposal of poorly treated sewage draining in the river pollutes the surface waters resulting in health hazard to the population along the river (Okalebo *et al.*, 2009). The abandoned sand quarry is used for the disposal of municipal solid wastes, yet the site is a water catchment area that drains into the Sosiani River (UNEP, 1998; Rotich *et al*., 2006). Furthermore, agricultural activities releases non-point chemical pollutants in the river, and much more, results to continual destruction of the riparian vegetation and biological diversity through clearing the ecotone. The wastewater from institutions and market within Eldoret town also reaches the river, All these anthropogenic activities generate wastes that drain directly or indirectly into the river affecting the structural and functional health of the ecosystem.

1.3. Justification

The bulk of communities along River Sosiani use the water for different purposes. The direct use for consumption without prior treatment are liable to water borne diseases. Chemical composition of different wastes from institutional discharge is of significant effect to the physiological and biochemical activities of both human and community structure of the organisms along the river channel. In addition, the human activities have resulted into deterioration of the riparian zone. Monitoring and evaluation of the level of pollution, the source of pollution and polluting agents is very important to safeguard the health effects to the water users who unsuspectingly uses the water without prior treatment. There is therefore a need for cost-effective monitoring protocol for the water quality of River Sosiani. Moreover, river water quality management plans require scientifically authentic data to inform management measures to be practiced by all stakeholders. The protocol developed for this river will help in the structure and methodology perspective in the assessment of other rivers within the area; for cost effective monitoring and evaluation of the anthropogenic activities degrading structural and functional integrity and therefore, the health of rivers in the upper catchment of Lake Victoria Basin, for rapid assessment, classification of water quality, policy formulation and implementation for conservation and management of the rivers and to meet the increasing demand for water supply to support population growth.

1.4. General Objective

To assess the health of River Sosiani using an integrated biomonitoring protocol

1.4.1. Specific Objectives

1) To determine the physical habitat characteristics of the riparian zone at different stations along River Sosiani
2) To evaluate the changes in physico-chemical water quality parameters along River Sosiani
3) To determine the changes in composition, abundance and diversity of vegetation communities along River Sosiani
4) To determine the change in composition, abundance and diversity of macroinvertebrate communities along River Sosiani.
5) To evaluate the responses of biological communities to the environmental and physico-chemical water quality parameters along River Sosiani.
6) To develop an integrated index for monitoring the health of River Sosiani.

1.5. Hypothesis

1. H_o There is no significant difference in water quality parameters among the sites along the river.
2. H_o Pollution has no significant effect on the composition, abundance and diversity of biological communities.
3. H_o The sensitivity of physical habitat, macrophyte and macroinvertebrate indces in River Sosiani does not vary significantly.

CHAPTER TWO

LITERATURE REVIEW

2.1. Physical Habitat

In a broad sense, habitat incorporates all aspects of physical and chemical constituents along with the biotic factors (Aadland, 1993; Casatti *et al.,* 2006; Fernandez *et al*., 2011) of a stream. However, physical habitat is the living space for all in-stream flora and fauna (Maddock, 1999; Barquin and Martinez-Capel, 2011), it is spatially and temporally dynamic and its condition and characteristics set the background for any assessment of the health of a waterway (Harding *et al.*, 2009). Physical habitat is regularly measured as part of a wide range of stream research, and resource activities in most parts of the world. Historically, physical habitat parameters have been commonly measured in order to classify or categorize river reaches (Snelder and Biggs, 2002; Snelder *et al*., 2004). However, in the recent decades, attempts have been made to use physical habitat parameters to assess and monitor the condition of lotic waterways (Maddock, 1999), based on the assumption that 'healthy' biotic communities that underlie well-functioning stream ecosystems are reliant on good habitat conditions.

Defining and characterizing river habitats is somewhat difficult, as rivers are highly complex structured ecosystems, which integrate processes occurring at different spatial and temporal scales. However, some of the ecological concepts that try to explain a river system have been developed to help in understanding, and can somehow depict processes in a river channel. Verdonschot, (2000) identifies nine of them as; first, the four dimensional lotic systems (longitudinal, latitudinal, vertical and temporal changes) and a catchment; spatial scale (Ward, 1989), second, the river continuum concept (longitudinal gradient) with a stream; valley spatial scale (Vannote *et al.,* 1980), third, serial discontinuity concept (discontinuity through human interface) with a spatial scale focusing on the stream (Ward and Starnford, 1983b), fourth, nutrient spiraling concept (longitudinal nutrient cycling) and stream, valley spatial scale (Wallace *et al.,* 1977), fifth, flood pulse concept (lateral exchange of substances) and lower reach, valley spatial scale (Junk *et al*., 1989), sixth, habitat template concept (r, K. A section in space and time) and stream section spatial scale (Southwood, 1977), seventh, patch dynamic concept (competition verses disturbance) and a stream section spatial scale (Townsend, 1989). The second last being the dynamic equilibrium concept (dynamic equilibrium system) with independent spatial scale (Huston, 1979) and lastly, intermediate disturbance hypothesis (no equilibrium maximizes diversity) independent spatial scale (Ward and Starnford, 1983a).

Some physical characterization have therefore been done along rivers, and they include; documentation of general land use, description of the stream origin and type, summary of the riparian vegetation features, and measurements of in-stream parameters such as width, depth, flow, and substrate (Harding *et al.,* 2009). In a stream channel where sampling sites are not physically comparable, habitat characterization is properly important for proper interpretation of bio-survey results (Roux *et al.,* 1993). Since, due to the spatio-temporal dynamism of a stream channel, the assessment sites can vary. However, a wide array of methodologies have been developed everywhere, for the assessment of stream channels, from the basin (Rosgen, 1996) to the microhabitat scale, PHABSIM (Bovee, 1996).

From the biological point of view, physical habitat assessment is seen as an indirect evaluation method based upon well-known relationships between abiotic and biotic components of river systems (Muhar and Jungwirth, 1998). The hypothesis being, the assessment of physical habitat criteria allows the determination of the potential of aquatic habitats to ‘support and maintain a balanced community of organisms having a species composition and functional organization comparable to the natural habitat of the region’ (Karr and Dudley, 1981).

In aut-/synecological studies, detailed habitat analyses are designed to explore functional relationships between organisms and their specific demands on the physical environment. Flow velocity, substrate composition, water depth and the percentage occurrence of various in-stream structures (e.g. undercut banks, overhanging vegetation, root wads, woody debris) are all parameters that are frequently used to describe and evaluate habitat conditions for aquatic biocoenoses. At the same time, habitat assessment on a larger spatial scale has become increasingly important in evaluating the health of the aquatic environment and documenting the proportion of impaired versus natural rivers.

Studies on physical habitat characteristics show that, they are an extremely important factors determining the structure and composition of fluvial biological communities and ecosystem functioning (Casatti *et al.,* 2006; Diana *et al.,* 2006; Rowe *et al.,* 2009; Johnson and Arunachalam, 2010; Barquin and Martinez-Carpel, 2011).

Many protocols are applied around the world, including descriptors, which describe the stream micro/macro features, riparian condition, and bank structure. The assessments performed being a general description of the site and a physical characterization in relation to water quality assessment. These have been employed to develop habitat index in relation to the physical habitat characteristics in focus. For instance, Casatti *et al.* 2006 uses mean velocity, mean depth, amount of riparian coverage (absent, present, or abundant), amount of marginal vegetation in contact with water (absent, present, or abundant), and predominant substrate (sand, sand/gravel, or sand/gravel/woody debris) to develop habitat Index. Assessment of the riparian

2.2. Stream Physico-chemistry

River water physico-chemistry is controlled by numerous natural and anthropogenic factors (Alberto *et al*., 2001; Simeonov *et al*., 2003; Ahearn *et al.*, 2005; Li *et al.*, 2008: 2009). Their effect in physical and hydrochemistry, which can either be from a diffused or point source (Sliva and Williams, 2001; Li *et al*., 2008) has resulted in deterioration of water quality in the past decades (Carpenter *et al.*, 1998; Liu *et al.*, 2003). Many studies have focused on the relationship between water quality and anthropogenic activities (Silva and Williams, 2001; Turner and Rabalais, 2003; Ahearn *et al*., 2005; Li *et al.*, 2008: 2009) such as industrial effluents and wastewater treatment facilities, and diffused sources such as runoffs from urban area and farming land (Carpenter *et al.,* 1998; Sliva and Williams, 2001; Liu *et al.*, 2003; Li *et al.*, 2008: 2009). They have focused on the environmentally relevant information that accounts for the pollution effect (Vignati *et al.*, 2010).

The assessment of physical and chemical variables of lotic systems provides some insight into their water quality (Bere and Tundisi, 2010). In most cases, this method allows only instantaneous measurements, therefore restricting the knowledge of water conditions to the period when the measurements were taken. This is because, the chemistry at any given time is a snapshot of the water quality at the time of sampling, and does not take into account, the temporal variation of water quality in lotic environments (Bere and Tundisi, 2010). However, since, the initial effect of pollutants is to degrade the physical quality of the water (Ewa *et al*., 2011) followed by the chemistry and the biological communities. The usual situation in the assessment of water quality is the measurement of multiple parameters, taken at different monitoring times, and from many monitoring stations. (Chapman, 1992; Alberto *et al*., 2001; Simeonov *et al*., 2003).

Most physico-chemical water quality parameters are sampled *in situ* and they include pH, dissolved oxygen, biological oxygen demand (BOD), temperature, conductivity, turbidity, total dissolved solids, and discharge or flow measurements (EPA Victoria, 2003; Simeonov *et al.,* 2003; Boustani and Hojati, 2010; Ewa *et al.,* 2011; Kumari *et al.,* 2011; Simpi *et al.,* 2011). Others that are determined calorimetrically are Chlorides, sulphate, phosphate, nitrate and ammonia and have been found to widely fluctuate depending on climatic conditions (Eleftheria *et al.,* 2000; Izonfuo and Bariweni, 2001).

2.3. Responses of Biological Communities to the Environmental and Physico-Chemical Water Qualiy

The response and sensitivity of different levels of taxa (Wunsam *et al.,* 2002; Nijboer *et al.,* 2005; Bilton *et al.,* 2006) and organism indices (Paavola *et al.,* 2003; Hering *et al.,* 2006; Torrisi *et al.,* 2010),to pollution (Clapcott *et al.,* 2010; Marzin *et al.,* 2012) are well documented. Their response to, and pollution evaluation varies (Reece and Richardson, 2000) and therefore, ideal bio-indicator qualities have been suggested

(Simpson, 2000; Zhou *et al.,* 2008). Identification and classification of biological communities precede indicator development (Cohen *et al.,* 2005). A reference site against which other sites' biotic community composition are compared (Simon *et al*., 2000; DeKeyser *et al*., 2003; Jones, 2008), being the basis for evaluation of the level of pollution and indicator sensitivity to the changing physico-chemical water quality parameters measured. This is because of the well-documented assessment protocols for biological community response to environmental changes in rivers/streams (Barbour *et al.,* 1999) that can be used, through biological integrity response/sensitivity to evaluate these differences.

2.3.1. Bioindicators and Metric Development

Bio-indicators are living entities quantifiable to assess status and trend in key ecological attributes, and should meet the criteria of being measurable, precise, consistent, relevant and sensitive (Gregory *et al*., 2005; Niemeijer and de Groot, 2008; van Strien *et al.,* 2009) to ecological changes. They range from multi-metric indices, univariate indices, standard zoological and botanical indicators, to predictive models (Simpson, 2000).

Metric development necessitates use of standard methods for the biological criteria (Simpson, 2000; Simon *et al.,* 2001) in sample collection (Hering *et al.,* 2006) and processing (Barbour *et al.,* 1999; Mandaville, 2002; Cohen *et al.,* 2005). Since Rivers are hierarchical and multivariate in complexity, multiple organism group indicator approach provide a more comprehensive ecological image of their health (Hughes *et al*., 2009), assuming that, different life history strategies of different communities will respond (in a measurable or quantifiable way through structural or functional changes in the community assemblage) to different types of stressors, providing complementary and comprehensive information on ecological status and pressures affecting the system (Paavola *et al.,* 2003; Hering *et al*., 2006; Meador *et al.,* 2008; Hughes *et al*., 2009),which in most cases (Kallimanis *et al.,* 2012), but not always, sensitive at higher taxa, (Wunsam *et al*., 2002; Landeiro *et al.*, 2012).

Assessment of rivers have been studied in relation to physico-chemical parameters and biological communities such as diatoms (Feio *et al.,* 2009; Lavoie *et al.,* 2009; Lange *et al.,* 2011; Delgado *et al.,* 2012; Kireta *et al.,* 2012), macroinvertebrates (Duran, 2006; Kobingi *et al.,* 2009; Aura *et al.,*2011), Macrophytes (Ferreira *et al.,*2005; Mackay *et al.,* 2010; Demars *et al.,* 2012) and a combination of some of these bio-monitors (Paavola *et al.,* 2003; Hering *et al.,* 2006; Torrisi *et al.,* 2010) whose results have evaluated human effect due to pollution on the aquatic ecosystems concerned. Furthermore, biological parameters are increasingly studied as more sensitive indicators of ecosystem integrity than physico-chemical parameters (Craft *et al*., 2007; Flinders *et al*., 2008; Smith *et al*., 2007).

2.4. Composition Abundance and Diversity of Macrophytes

The heterogeneity nature of streams with differences in physical and chemical environmental parameters results to dynamic stream macrophyte communities with natural changes in species composition and abundance (Dawson *et al.,* 1978; Biggs, 1996; Baattrup-Pedersen and Riis 1999). Studies worldwide indicate that the knowledge of the macrophyte species composition and abundance provides important information on the aquatic ecosystem (Baattrup-Pedersen *et al*., 2003; Grimbega, 2011), as they are a key component in the functioning of streams where they grow in relatively high abundance (Sand-Jensen *et al*., 1989; Clarke and Wharton, 2001). The distribution of macrophytes in streams is largely influenced by substrate and flow velocity while, the growth of macrophytes has important impacts upon flow resistance, Flow velocities, and sediment dynamics.

The most commonly cited abiotic determinants of aquatic macrophyte assemblage structure are all flow-related factors (e.g., flow extremes, flow regime, hydraulics, substrate composition, and stability). Spatial and temporal variation in plant assemblage structure is influenced by flooding and scouring, desiccation, substrate stability and localized variations in water velocity, turbulence and shear stress (Chambers *et al.*, 1991, Biggs, 1996, French and Chambers, 1996). Aquatic macrophytes typically have patchy distributions as a result of spatial variations in disturbance frequency and intensity, colonization success and growth rates (Sand-Jensen and Madsen, 1992).

Macrophytes are important for the production of oxygen, control of water quality by buffering nutrient influx, stabilizing sediment and sheltering growth of aquatic organisms (Mohan and Hosetti, 1999). They are therefore important indicators of environmental conditions and long-term ecological changes that can integrate the temporal effects of disturbances (Tremp and Kohler, 1995; Hering *et al*., 2006), as they are sensitive to physical and chemical changes in the ecosystem (Solimini *et al.*, 2008; Tamira and Mengistou, 2012). For an assessment of the ecological status of a stream using macrophytes, the variability of macrophyte richness is linked to physical factors in the environment, which make an important contribution to the pattern of macrophyte distribution (Abou-Hamdan *et al*., 2005).

2.5. Composition Abundance and Diversity of Macroinvertebrates

The composition, diversity and abundance of benthic invertebrates are affected by several factors in a spatio-temporal scale (Subramanian and Sivaramakrishnan, 2005); both natural and anthropogenic. Among them includes the heterogeneity of the stream habitat (Maddock, 1999), stream flow (riffles, pools, runs cobbles) (Minshall, 1984; McCain *et al.*, 1990; Scarsbrook and Townsend, 1993; Subramanian and Sivaramakrishnan, 2005), substrate type, size and stability (Allan, 1995), and the amount of trapped detritus on the substrate (Subramanian and Sivaramakrishnan, 2005) which are food for the organisms.

The intensity, frequency, and disturbance due to anthropogenic activities also determine the abundance, diversity and species richness of community assemblage (Townsend *et al*., 1997; McCabe and Gotell, 2000). Increasing disturbance intensity may remove more individuals, more species, and more of the food resources necessary for recolonization (Huston, 1979), a range of pollution effects on the organisms have been studied (Duran, 2006). Macroinvertebrate community structure reflects a combination of the physical, chemical and biological characteristics of their habitat and therefore their use as key indicators of freshwater ecosystem health (Bonada *et al*., 2005). Community analyses of macroinvertebrates have also become standard methods for assessing changes in environmental conditions over a variety of spatial and temporal scales (Walker, 2001; Porinchu and MacDonald, 2003; Álvarez-Cabria *et al*., 2010).

Since benthic macroinvertebrates are considered the best biological indicators of water, and their responses to organic pollutants have been used to develop contemporary biotic indices (Elephtheria *et al*., 2000; Nijboer *et al*., 2005; Duran, 2006), especially the chironomid community (De Bisthoven *et al*., 1998; Carew *et al*., 2007; Raunio *et al*., 2007; Greffard *et al*., 2011), they have been widely studied and even narrowed to single taxon in bio-monitoring (Paavola *et al*., 2003; Greffard *et al*., 2011), and of late, their biology; anatomy, physiology etc. are in focus. They are also considered as important assessment indicators for the effects of multiple stressor types such as organic pollution (Statzner *et al*., 2001) hydro-morphological degradation (Buffagni *et al*., 2004; Lorenz *et al*., 2004), acidification (Townsend *et al.*, 1983; Sandin *et al.*, 2004) and general stress (Barbour *et al*., 1998; Dole´dec *et al.*, 1999; Karr and Chu, 1999). However, high impact due to human activities caused many changes in the assemblages and biodiversity of the river fauna (Nedeau *et al*., 2003).

2.6. Integrated Index for Monitoring River Habitat Health

An integrated index for assessing river health with large number of metrics at different stressor gradients and indicators necessitates correlation of the parameters, to reduce the candidate metrics to a smaller number by removal of redundant metrics with closely similar correlation coefficient (Hering *et al.*, 2006). The stressor gradients can be defined by the pollutants (Marzin *et al.*, 2012), and the pollution effect at these gradients delineated for the physico-chemical parameters by multivariate analysis (Dahl LuCke and Johnson, 2009; Primpas *et al.*, 2010). Furthermore, metrics with strong linear relationship with the pollution effect (environmental measurements) can be determined by the correlation/regression analysis through r/r^2 computation (Skoulikidis *et al* 2004; Wilson and Bayley, 2012). Finally, an integrated approach that adopts a group of relevant metrics; physical, chemical and biological variables, may prove most effective at evaluating river health (Boulton, 1999).

Due to the rapidly growing human population, wise management of freshwater ecosystems is an important task globally (Gleick, 2002; Vorosmarty, 2002). There is a critical challenge on how to support national development goals and protect an increasingly degraded environment (King and McCartney, 2007; United Nations, 2007). A cost effective assessment method that incorporates ecosystem health indicators needs an integrated approach (King and Brown, 2010) for evaluation. Such as physical habitat, physico-chemical water quality and biologic index that become the mainstream method of studying river health (Meng *et al.*, 2009). Such an assessment method is necessary for the upper catchment of Lake Victoria Basin Rivers with multiple human activities that deteriorates river health at varying intensity, such as River Sosiani.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study Area

River Sosiani catchment lies between latitudes 00^0 17' N and 00^0 32' N, and longitudes 35^0 32' E and 35^0 13' E. It has 21 sub-catchments and is bound in the South-east by the Elgeyo escarpment and in the North-west by Uasin-Gishu plateau in the Rift-Valley province in Kenya (Chibole, 2013). The River occurs within Uasin-Gishu County; running through from Eldoret east towards Eldoret north, at an altitude of 1800-2100 m above sea level. The river has an area of 225 km^2, perimeter of 88 km, total number of streams 15, and of order 2 according to (Chibole, 2013). The average temperature of the area is 16.6 °C, the warmest average high temperature is 26 °C in February and March while the coolest average low temperature being 9 °C. The average annual precipitation ranging between 1103 mm or 92 mm per month. The month with the driest weather is January with mean of 29 mm of rainfall across 5 days, while the month with the wettest weather is August (196 mm of rainfall) across 21 days. The mean relative humidity for an average year is 46.9% and on a monthly basis; it ranges from 33% in February to 62% in August. Hours of sunshine range between 5.8 hours per day in August and 9.2 hours per day in February (http://www.eldoret.climatemps.com)

3.2. Experimental Design

The location of the six sampling stations along River Sosiani are shown in Figure 1. The first station (St 1) that represented the reference site was at Cheboen Dam. The second station (St 2) was at Elegrin Dam, sampled before and after the dam and had farming activities; especially, large-scale cattle ranching. Station 1 and St 2 were 21 km apart, the distance before and after the sampling sites at St 2 was 1.2 km, with Elegrin Dam 0.7 km long. Sampling sites were near a bridge, and were determined by accessibility of the area.

The third station at Two Rivers Dam (St 3) was also sampled before and after the dam; it had agricultural practice including commercial flower farming. Station 2 and St 3 were 8.1 km apart while the distance before and after sampling sites at St 3 was 1.5 km, with Two Rivers Dam 1.1 km long, here too, the sampling sites were determined by accessibility of the area. Station 4 (St 4) was at Annex bridge where tree nursery, suface runoffs from the road and car-wash activities were the major factors of ecosystem degradation. Station 3 (St 3) and St 4 were 5.2 km apart.

The fifth station (St 5) was at Huruma, sampled before and after the sewage treatment ponds, while the last station (St 6) was at Maili inne, an assumed recovery station along the river. Station 4 and St 5 were 7.5 km apart, the distance before and after sampling sites at St 5 was 1.2 km, and the sewage treatment ponds covered about 0.87 km along the river. Finally, St 5 and St 6 were 2.8 km apart. The sampled parameters were physical habitat characteristics, physico-chemical water quality parameters, macroinvertebrate assemblages and vegetation species which were sampled from August 2012 to Noveber 2012 being the wet season and December to February 2013 for the dry season.

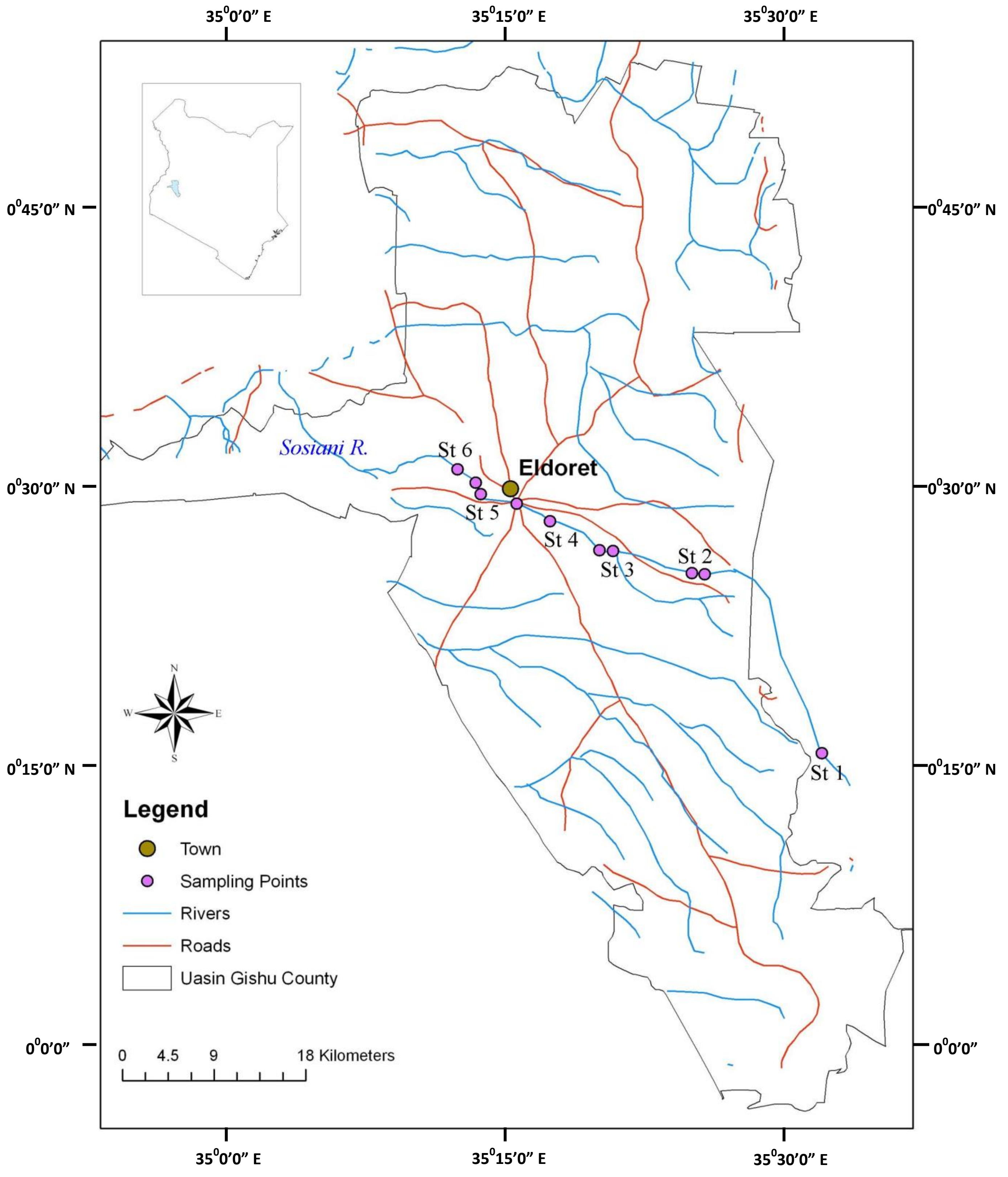

Figure 1: Map showing the sampling stations used during the study period.

The Plates 1 to 5 shows some of the habitat characteristics of the sampling stations along River Sosiani during the study period.

Plate 1: Stream at the reference station Cheboen; St 1 (Source: Author, 2013)

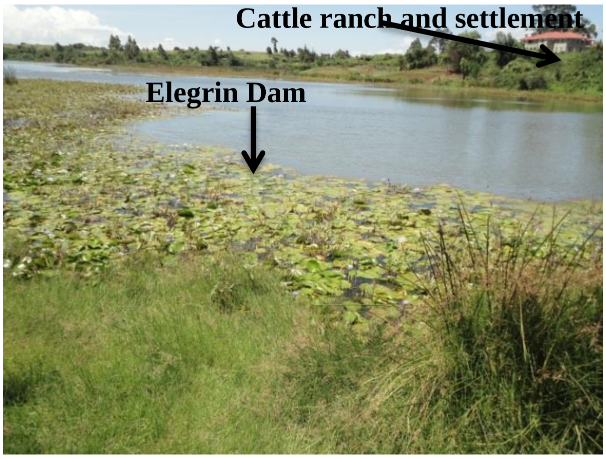

Plate 2: Elegrin Dam near large-scale cattle ranch; St 2 (Source: Author, 2013)

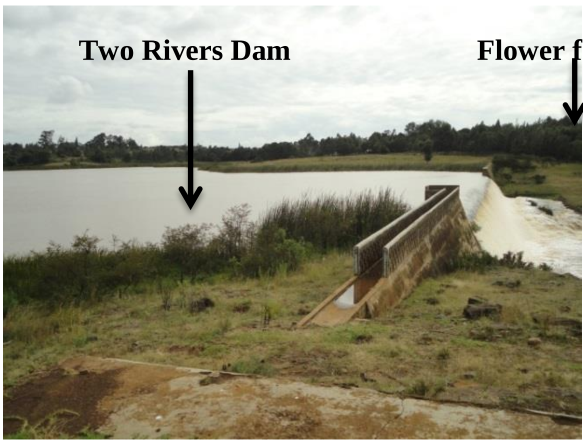

Plate 3: Two Rivers Dam near the flower farm ; St 3 (Source: Author, 2013)

Plate 4: Human activities at Annex Bridge; St 4 (Source: Author, 2013)

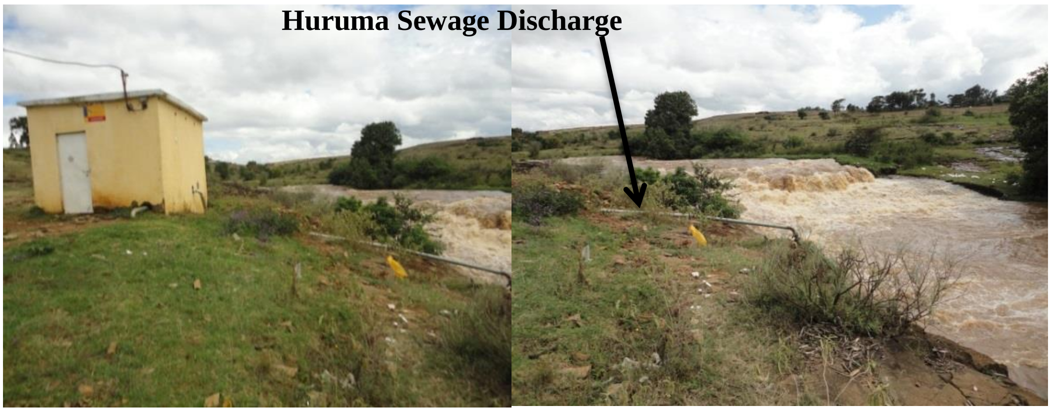

Plate 5: River Sosiani before Huruma sewage ponds (Source: Author, 2013)

3.2.1. Physical Habitat Characteristics

A 50 m tape-measure was used to measure width of the river channel at each station, being measured perpendicular to the river; from one bank to the other. The tape was held tight, just above the water surface, at the edge of land water interface (Frimpong *et al.,* 2005). This was done for both wet and dry season and the average width computed from the two measurements. A GPS was used to take the co-ordinates of the sites and elevation from which, the distance from one site to the other and the gradient were computed. Photographs were also taken using a camera. Finally taking records of different physical features of the river and human activities that were being practiced at and around the sampling stations.

The physical habitat index was developed according to Meng *et al.,* 2009. Since there were three divisions of physical habitat degradation, the category used were direct (6), marginal (3) and optional (1) depending on how they also affected the water quality of River Sosiani. The first category of score 0.6 = 6/10 ≡ (6+3+1) represented the direct (point-source) pollution influence from the municipal activity which had a high impact on water quality, the second category (0.3) represented non-point pollution resulting from the agricultural activities mainly of nutrient loading into the river, and the third category (0.1) represented the human disturbance activities observed along the riparian zone. Habitat index (HI) was calculated for each station with the parameters categorized in each level, and the equation used was:

$$HI = \sum_{n}^{i} \frac{\sum Mi + Ai + Hi}{\sum N \max} \quad \text{(eqn 1)}$$

Where; *HI = the Habitat index*

Mi = the level/score of municipal activities

Ai = the level/score of agricultural activities

Hi = the level/score of the human disturbance activities

N = the maximum level or score (10)

Diversity, dominance and evenness of biological communities (macrophytes and macroinvertebrates) were also incorporated into the HI in order to develop the final Habitat Index for River Sosiani (HIRS). The final equation for calculating HIRS was:

$$HIRS = HI + \frac{Si}{S\max} + \frac{Di}{D\max}$$ ……..…………………………… (eqn 2)

Where; *HIRS = represented the Habitat Index for River Sosiani*

HI = the habitat index

Si = the Richness diversity for either macrophytes or macroinvertebrate

Di = is the species dominance (macrophytes and macroinvertebrates)

Smax = maximum species richness and

Dmax= maximum species dominance

3.2.2. Physico-chemical Water Quality Parameters

Standard methods of measurements for water quality parameters were used (APHA, 1998). Triplicate samples were taken at each sampling site, and before and after method used for sampling the parameters (Underwood, 1992) at the main pollution influenced sites, which were either separated by a dam or sewage treatment ponds. The parameters measured *in situ* using a hydro-lab, YSN professional series model, ProtoComm II L/N 12G100510 were Temperature, pH, Conductivity and Total Dissolved Solids (TDS) (Pejman *et al.*, 2009; Ayeni and Soneye, 2013). Sampling bottles (250 ml) with stoppers were used for Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD) while 500 ml plastic bottles were used for Total Phosphorous (TP) and Total Organic Nitrogrn (TON).

The DO samples were fixed at the sites using Alkaline Iodide, Manganese Sulphate and Sulphuric acid and later lab analyzed through titration with Thiosulphate solution. The BOD samples were wrapped with opaque papers and fixed (Alkaline iodide, Manganese sulphate and sulphuric acid) after 5 days, followed by titration with

Thiosulphate solution; Winkler Method (Khana and Bhutiani, 2008), to determine the amount of oxygen present after 5 days. This was then subtracted from the amount of oxygen (DO) at each site during sampling, in order to determine the amount of oxygen consumed after the 5 days (APHA, 1998). Dissolved oxygen concentration (mg/l) was calculated using the following fomula:

$$DO(mg/l) = \frac{V_1 \times N \times 8 \times 1000}{\frac{V_4(V_2 - V_3)}{V_2}} \quad \text{.................. (eqn 3)}$$

Where; V_1*= Volume of the titrant*

V_2 *= Volume of sampling bottle after placing the stopper*

V_3 *= Volume of Manganese sulphate +Potassium iodide solution added*

V_4 *= Volume of the fraction of the contents used for titration*

N = Normality of the titrant

8= Equivalent weight of Oxygen

Samples used to determine TP concentration were preserved with concentrated Sulphuric acid, followed by digestion of each sample for about one and a half hours on a hot plante. Sodium hydroxide was added to neutralize the acid used in digestion and freshly prepared mixed reagent (125 ml concentrated Sulphuric acid, 37.5 ml ammonia molibdate, 75 ml Ascorbic acid and 12.5 ml potassium antimonyl tartate solution) added to the samples, and finally subjected to spectrophotometry at 880 µm wavelength standardized with distilled water. Intensity of the blue color indicating the amount of TP in the samples. Spectrophotometer reading was then subtracted from the standard reading from the distilled water and TP concentration evaluated from these values (APHA, 1998).

Total organic nitrogen samples were also preserved with concentrated sulphuric acid followed by Kjelda method (Khana and Bhutiani, 2008). Sodium hydroxide solution was added to samples after digestion, to neutralize the concentrated sulphuric acid. Samples were then treated with 100 ml distilled water followed by 50 ml thiosulfate. The reaction results to ammonium sulphate $(NH_4)_2 SO_4)$ and distillation in a Liebig condenser, releasing ammonia gas, which was trapped in 50 ml boric acid (a weak acid). A purple color change indicated the success of this reaction. The results were finally titrated with weak sulphuric acid to form ammonia phosphate and the determination of TON was done by calculations from these titers (APHA, 1998). The final evaluation of the *in vitro* analysis for TON (mg/l) was done using the following equations:

$$TON(mgl^{-1}) = \frac{A - B \times 1000 \times 14}{V} \quad \text{……………………….. (eqn 4)}$$

Where; *TON= Total Organic Nitrogen*

A=Volume of acid (H_2SO_4) used against sample.

B= Volume of

N=Normality of acid

V= Volume of sample

14= Equivalent weight of Nitrogen

3.2.3. Sampling Macroinvertebrates

Composite samples were collected at each sampling site at rifles, runs and pools. A scoop net of 0.5 mm was used for sampling and the samples were collected in labelled plastic bottles. These were further preserved with ethanol 0.5 % and taken to the laboratory. The samples were sieved and a forceps was used to pick macroinvertebrate while being observed with a hand lens (x 10). Identification was done using macroinvertebrate identification protocols (Gerber and Gabriel, 2002) to the lowest taxonomic group identifiable.

3.2.4. Sampling Vegetation

Identification and classification of the plants were done at each site, which included taxonomic and non-taxonomic grouping. Non-taxonomic grouping involved four categories; i) Habit (algae, climbers, creepers, erected herbs…); ii) Submersed plants, free floating plants or emergent plants, iii) Habitat (terrestrial, semi-aquatic and aquatic plants) along the riverine wetland, and iv) Plant status (indigenous or exotic). Taxonomic classification majorly observed the floristic part of the plant, but also their fruits, seeds and leaves (pattern and shape) for identification. Plant species were recorded and their photographs taken for precision in identification from plant classification records. Sampling done according to modified Hering *et al.,* 2006 and Marzin *et al.,* 2012.

3.3. Data Analysis

3.3.1. Descriptive and Univariate Analysis

Mean, standard errors, standard deviation, line-graphs, bar graphs and table (Classical analysis methods) were calculated for data cleaning and 'noise' reduction and trend observation (Shrestha and Kazama, 2007; Boyaciouglu and Boyaciouglu, 2008; Zhang *et al.,* 2010). Relative abundance of taxa were calculated using Minitab 16 and Microsoft excel 2013 for comparison and prior analysis of any uniqueness in the biological communities at different pollution gradient. Simpson diversity, Evenness and Dominance indices were then computed for both macrophytes and macroinvertebrates using PAST statistical software. Temporal variations in water quality was evaluated using Spearman's rank (R) coefficient, a non-parametric test often used to evaluate the correlation structure between water quality parameters with non-normal distributions (Zhou *et al*., 2007).

3.3.2. Multivariate Techniques, Abundance and Sensitivity of Biological communities

Since most multivariate statistical methods require that the data conform to normal distribution (Lattin *et al*., 2003; Papatheodorou *et al*., 2006; Zhang *et al.,* 2010), the normality test was done by analyzing statistical values of kurtosis and skewness. Log transformation was necessary to fit the normality test (Kowalkowski *et al*., 2006; Papatheodorou *et al*., 2006; Zhang *et al.*, 2010). The log transformation of water quality parameters was expressed as:

$$x \equiv Log_{10} x \quad \text{(eqn 5)}$$

Where x represented each of the measured water quality parameter.

Principal component analysis (PCA) was used in data reduction technique, to explain most of the variance in the data while reducing the number of variables to a few uncorrelated components **(**Helena *et al*., 2000; Wunderlin *et al*., 2001; Jolliffe, 2002; Boyaciouglu and Boyaciouglu, 2008; Wu and Kuo, 2012) using Biplot in Microsoft Excel 2010**.** Screen plot was done to examine the number of significant components at 95 % level of significance.

The PCA equation was expressed as follows:

$$PC(z_{ij}) = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} ....a_{im}x_{mj} \text{ ……………..……. (eqn 6)}$$

Where; *z = component score*

a = the component loading

x = the measured value of variable

i = is the component number

j = the sample number and

m = the total number of variables.

The PCs were subjected to varimax rotation generating varifactors (VFs) (Brumelis *et al*., 2000; Love *et al*., 2004; Abdul-Wahab *et al*., 2005; Pejman *et al.*, 2009), which were useful tools for extracting latent information, to discriminate parameters with large load values using Minitab 16. Factor analysis (FA) was expressed as:

$$FA(z_{ji}) = a_{f1}f_{1i} + a_{f2}f_{2i} + a_{f3}f_{3i} ....a_{fm}f_{mi} \text{ …………. (eqn 7)}$$

Where; *z = measured variable*

a = factor loading

f = the factor score

e = the residual term accounting for errors or other source of variation

i = the sample number and

m = the total number of factors.

Cluster analysis (CA) of the stations, with water quality parameters was evaluated with euclidean distance (Zhang *et al.*, 2010). The data was normalized by Ward's method; an analysis of variance approach to evaluate the distances between clusters in an attempt to minimize the sum of squares (SS) of any two clusters that can be formed at each step (Shrestha and Kazama, 2007; Zhou *et al.*, 2007). This was done for both wet and dry season mean measurements to search for natural groupings among stations to discover latent structures present in the data set (Sun *et al*., 2011; Wu and Kuo, 2012). Cluster analysis divides a large amount of cases into smaller groups based on the characteristics they possess (McGarial *et al*., 2000; Simeonov *et al*., 2003; Kowalkowski *et al*., 2006). The abundance and sensitivity of Aquatic, Semi-aquatic and Riverine vegetation was also analyzed at the sampling stations and along the changing concentration of TON and TP (mg/l). Macroinvertebrate families were also compared for their optimum concentration and tolerance due to TON, TP and BOD mean measurements using PAST statistical software.

3.3.3. Developing of Pollution Metric for River Sosiani

A modified Nutrient Pollution Metric; NPM (Skoulikidis *et al* 2003; 2004) was used to develop Pollution Metric for River Sosiani (PMRS) to evaluate pollution effect due to physico-chemical water quality parameter concentrations at the sampling stations. Principal Component Analysis was carried out on the mean seasonal values of three water quality parameter measurements (TON, TP and BOD). Pollution Metric for River Sosiani (PMRS) was calculated for each site using the score of the first axis of the PCA (PC1).

The algorithm for the calculation of PMRS being as follows:

$$PMRSi = \frac{PC1i}{\max\{PC1\}} \text{ .... (eqn 8)}$$

Where; *PMRSi =Pollution metric for River Sosiani at each site*

PC1i = Principal component 1 vector displacement of site I and

maxPC1 = Maximum vector dispalacement of principal component 1

Spearman's correlation of the PMRS for both wet and dry season was done to investigate the relationship between the PMRS and the selected water quality parameters (TON, TP and BOD) for both wet and dry seasons (Table 1). The r-values and the significance of these parameters were then compared for the wet and dry season PMRS, and the final PMRS for the river was computed as the average of the two seasons.

Table 1: PC Class and the score in each Quality class
PC class≡ PMRS

PC Class	Quality Class	Score
0-0.2	Excellent	1
0.21-0.4	Good	0.8
0.41-0.6	Moderate	0.6
0.61-0.8	Poor	0.4
0.81-1	Bad	0.2

3.3.4. Developing of the Biotic Index for River Sosiani Health

Biotic Index for River Sosiani Health (BIRSH) was then calculated. Based on the PC class, the sites were grouped into the quality class and scores assigned to them depending on the range of PC class they belonged to. The macrophyte species and macroinvertebrate families corresponding to each quality class were identified separately for each sampling station. There were taxa found only in one quality class, species/families found in two quality classes and others found in three or four of the quality classes. Each taxon was then evaluated according to its presence in different quality classes, by taking the average of the values of each class. For instance, a taxon found only in quality class Good, Scored 0.8 and a taxon in quality class Good, Moderate and Bad scored (0.8+0.6+0.4)/3 = 0.6.

Algorithm for calculating BIRSH was as follows:

$$BIRSH = \frac{\sum_{i}^{N} sci}{\sum_{i}^{N} ai}$$ ………………………………………….…………… (eqn 9)

Where; *sci = Score of the ith taxon and*

ai = total number of taxon

Biotic Index for River Sosiani Heath was developed for both macrophytes and macroinvertebrates as follows; Macrophyte Index for River Sosiani Health was determined using the formula:

$$MpIRSH = \frac{\sum_{i}^{N} Mp_i}{\sum_{i}^{N} ai}$$ …………………….……………………….. (eqn 10)

Where; *MpIRSH = the macrophyte index for River Sosiani Health*

Mp_i *= the score of the ith macrophyte taxon*

ai = total number of taxon

While Macroinvertebrate Index for River Sosiani Health (MinvIRSH) was developed using the formula:

$$MinvIRSH = \frac{\sum_{i}^{N} Minv_i}{\sum_{i}^{N} ai} \quad \text{...} \quad \text{(eqn 11)}$$

Where; *MinvIRSH = the macroinvertebrate index for River Sosiani Health*

$Minv_i$ = the score of the ith macroinvertebrate taxon

ai = total number of taxon

3.3.5. Integrated Index for River Sosiani Health

Integrated index for River Sosiani Health (IIRSH) was then developed with the scores derived from water quality class represented by PMRS, HIRS, MpIRSH and MinvIRSH; the last two indices falling under (BIRS).

$$IIRSH = \sum_{i}^{n} \frac{HIRSi + MpIRSH_i + MinvIRSH_i}{n} \quad \text{....................} \quad \text{(eqn 12)}$$

Where; *$HIRS_i$ = the Habitat index value for each station*

$MpIRS_i$ = the Macrophyte index value for each station

$MinvIRS_i$= the Macroinvertebrate index value for each station and

IIRSH= the integrated index for River Sosiani Health

CHAPTER FOUR

RESULTS

3.4. Physical Habitat Description

Table 2 shows the width of River Sosiani and GPS co-ordinates at the sampling stations during tudy period. The width of the river was minimum at the first station (0.3± 0.1 m) and widened downstream at St 3 after Two Rivers Dam (14.3 ± 1.2 m), St 4 (10.6 ± 1.0 m), St 5 before Huruma sewage treatment plant (13.4 ± 1.1 m), St 5 after Huruma sewage treatment plant (10.6 ± 0.8 m), and St 6 (11 ± 0.5 m). The respective GPS co-ordinates at these stations are also shown.

Table 2: Width and GPS co-ordinates along River Sosiani during sampling period

Station	Width (m)±SE	Easting	Northing
ST 1 Cheboen	0.3 ± 0.1	0^0 17’ 24” N	35^0 32’ 31” E
ST 2 Bf Elegrin	9.7 ± 0.5	0^0 27’ 2” N	35^0 26’ 18” E
ST 2 Aft Elegrin	6.2 ± 0.8	0^0 27’ 5” N	35^0 25’ 38” E
ST 3 Bf Two Rivers	5 ± 0.4	0^0 28’ 16” N	35^0 21’ 27” E
ST 3 Aft Two Rivers	14.3 ± 1.2	0^0 28’ 18” N	35^0 20’ 44” E
ST 4 Annex	10.6 ± 1.0	0^0 29’ 53” N	35^0 18’ 7” E
ST 5 Bf Huruma	13.4 ± 1.1	0^0 31’ 19” N	35^0 14’ 26” E
ST 5 Aft Huruma	10.6 ± 0.8	0^0 31’ 56” N	35^0 14’ 10” E
ST 6 Maili inne	11 ± 0.5	0^0 32’ 40” N	35^0 13’ 12” E

Table 3 shows the evaluation of the slope from sampling St 1 downstream. The total distance between St 1 and St 6 was 48.5 km. Station 1 was at an altitude of 2566 m while St 6 was at an altitude of 1970 m. There was an altitude difference of 596 m between them. Compared to the other stations, the slope was steep at sampling points of St 2 (0.067) and between St 2 and St 3 (0.0142) and minimum between St 3 and St 4 (0.0087).

Table 3: Slope at sampling stations along River Sosiani during study period
Δ Dist≡ change in distance, Δ Alt≡ change in altitude, btw≡ between

Stations	Dist in km	Δ Dist km	Alt (m)	Δ Alt (m) btw St	Δ Dist (m) btw St	Δ Alt/ΔDist (btw St)
TSt 1	0	0	2566	0	0	0.0000
St 2 Bf	21	21	2305	261	21000	0.0124
St 2 Aft	22.2	1.2	2285	20	1200	0.0167
St 3 Bf	30.3	8.1	2170	115	8100	0.0142
St 3 Aft	31.8	1.5	2157	13	1500	0.0087
St 4	37	5.2	2099	58	5200	0.0112
St 5 Bf	44.5	7.5	2019	80	7500	0.0107
St 5 Aft	45.7	1.2	2005	14	1200	0.0117
St 6	48.5	2.8	1970	35	2800	0.0125

The relationship between distance and altitude was a linear regression model, of the form Altitude = -0.0123Distance + 2558 with an r^2 of 99.77 % (Figure 2). The total change in altitude from the first to the last station (596 m) had a distance difference of 48500 m, hence a gently slopping area with a negative distance coefficient (-0.0123) indicating that there was a reduction in altitude as the distance from St 1 increased. The highest point was relatively 2558 m as shown by the model intercept of the altitude scale, represented by the constant in the regression equation.

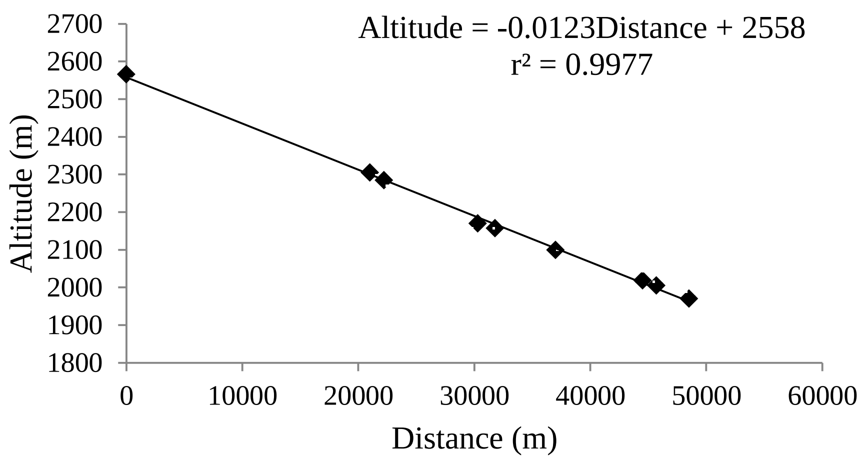

Figure 2: Distance against altitude along River Sosiani during the study period.

4.1.1. Indicators of Human Activities

Human activity indicators observed along the river were summarized in Table 4. They ranged from (i) Human disturbance; settlement, fencing, washing clothes, bathing, building bridges, damming, car wash, tree nursery, power plant, (ii) Farming activities of non-point pollution; Cattle grazing, cattle ranch, flower farms, vegetable and banana plantation, to (iii) Municipal activities (point source); sewage disposal, dumpsite and solid waste disposal in to the river.

Table 4: Indicators of Human activities at the riparian zone and the River habitat characteristics during the study period
1, 2, 3, 4,…..≡ human activities

Cheboen Dam (St 1)	Before Elegrin Dam (St 2)
Animal grazing (Cattle and sheep)[1]	Settlements [1]
Man-made dam (Cheboen) Wetland plants [2]	Cattle ranch [2]
Channeled for domestic use [3]	Animal grazing [3]
Shallow banks and river bed, with clear waters	Fencing [4]
Straight channel	Fetching water [5]
Plenty of grass along the river banks	Planting vegetable [6]
Tall trees and shrubs at the riparian zone	Bridge made of tree trunks [7]
Leaves and twigs transported	Translucent river with rocky bed
	Shallow river, straight channel and gentle slopping banks
	Shrubs and grass along the banks
After Elegrin Dam (St 2)	**Before Two Rivers Dam (St 3)**
Animal grazing [1]	Animal grazing [1]
Man-made dam [2]	Washing clothes [2]
Cemented bridge [3]	Farming [3]
Rocky bed and banks	Fencing [4]
Slightly deep opaque waters	Rocky bed with loam soil deposit at the banks
Sedges and grass with shrubs at the banks	Wadding River
Straight channel	Sedges and grass at the banks
Gentle to steep slopping banks	Shrubs and short trees at the riparian zone
	Slightly deep waters with steep banks

Table 4: Cont… Indicators of Human activities at the riparian zone and the River habitat characteristics during the study period
1, 2, 3, 4,…..≡ human activities

After Two Rivers Dam (St 3)	Annex Bridge (St 4)
Man-made dam after the wetland [1] Flower farm [2] Log treatment/preservation with tar [3] Fencing [4] Deep waters with steep banks Wadding River Grass along the banks Gentle slopping Recreational use Natural wetland	Main road (Tarmac)[1] Washing clothes [2] Car wash [3] Bathing [4] Tree nursery [5] KPLC power plant [6] Fencing [7] Settlements [8] Grazing [9] Deep and steep banks (over 1.5 m) Grass and trees with shrubs at the riparian zone Rocky bed with stones and pebbles at the banks Deep, opaque and wadding River
Town Bridge (Comparative site)	**Before Huruma sewage (St 5)**
Washing [1] Bathing [2] Juakali workshops [3] Burning wastes [4] Metallic Bridge [5] Vegetable plantation [6] Plastics and polythenes deposited on the river [7] Suspended solid wastes [8] Shallow to deep and steep banks Grass on the banks Straight channel	Grazing [1] Suspended solid wastes [2] Patchy grass and shrubs at the bank [3] Fencing [4] Vegetable plantation [5] Murram road [6] Grazing (Cattle sheep and pigs)[7] Dumping site [8] Waste deposit at the pool [9] Odorous, dirty brown water with foams [10] Cactus at the riparian zone Gentle slopping to flat banks Rocky bed, riparian with stones pebbles and grit Wadding river Shallow bank, relatively steep slopping river channel
After Huruma sewage (St 5)	**Maili inne Bridge (St 6)**
Sewage ponds [1] Cattle rearing [2] Settlements [3] Banana plantation [4] Green, Odorous and opaque waters [5] Solid waste deposit at pools [6] Steep banks with deep river channel Rocky bed with stones and pebble deposit at the banks Protruding tree roots at the banks with trapped solid wastes Sand deposits at the banks Wide channel	Plantations [1] Settlements [2] Waste deposit at pools [3] Odorous water [4] Deep and steep banks Shrubs and grass

4.1.2. Habitat Index

Human disturbance (H) effects were grouped in the category ‘optional’ with score 0.1 (excellent water quality class), agricultural (A) effect were grouped in category ‘marginal’ with score of 0.3 (good water quality class) and municipal (M) effect were grouped in the category ‘direct’ with score of 0.6 (moderate water quality class) as in Table 5. The combination of these categories such as; municipal and human (M + H) = 0.7 were the range of scores and categorized in bad water quality class, or municipal and agricultural (M + A) = 0.9 which was of poor water quality class.

Station 1 had excellent water quality class; only human activities. Station 2 Aft and 3 Bf were majorly agricultural areas but St 2 Bf, St 3 Aft and St 4 had agricultural practices with human disturbance and so were categorized in good water quality class. Station 5 Aft had municipal wastes and human activities and was classified in poor water quality class, St 6 had municipal and agricultural activities and St 5 Bf had a combination of all the three categories and so, the two were classified to be of bad water quality. None of the stations had only municipal activities.

Table 5: Level of physical habitat degradation and water quality class

H≡ Human disturbance, A≡ Agricultural influence and M≡ Municipal influence

Stations	Category	Score	HI	Range of Score	Quality Class
St 1	*H*	1	0.1	0--0.2	Excellent
St 2 Aft, 3 Bf	*A*	3	0.3	0.21--0.4	Good
St 2 Bf, 3 Aft and 4	*H* + *A*	4	0.4	0.21--0.4	Good
--	*M*	6	0.6	0.41--0.6	Moderate
St 5 Aft	*M* + *H*	7	0.7	0.61--0.8	Poor
St 6	*M* + *A*	9	0.9	0.81—1	Bad
St 5 Bf	*M* + *A* + *H*	10	1	0.81—1	Bad

4.2. Physico-chemical Water Quality Parameter

4.2.1. Univariate Analysis

Figure 3a and 3b is a summary of the mean temperature and conductivity measurements respectively. Temperature rose from the upper catchment downstream, but dropped at St 6 in dry season. It was also higher during the dry season than the wet season. A similar trend was observed with conductivity. Its primary vertical axis represented the wet season and had the lowest mean measurement of 60 µS/cm with the highest mean measurement being close to 120 µS/cm. The secondary vertical axis depicted dry season measurements, and it ranged between 100 µS/cm and 500 µS/cm; the lowest being at the upper catchment stations while the highest was at St 5 and St 6.

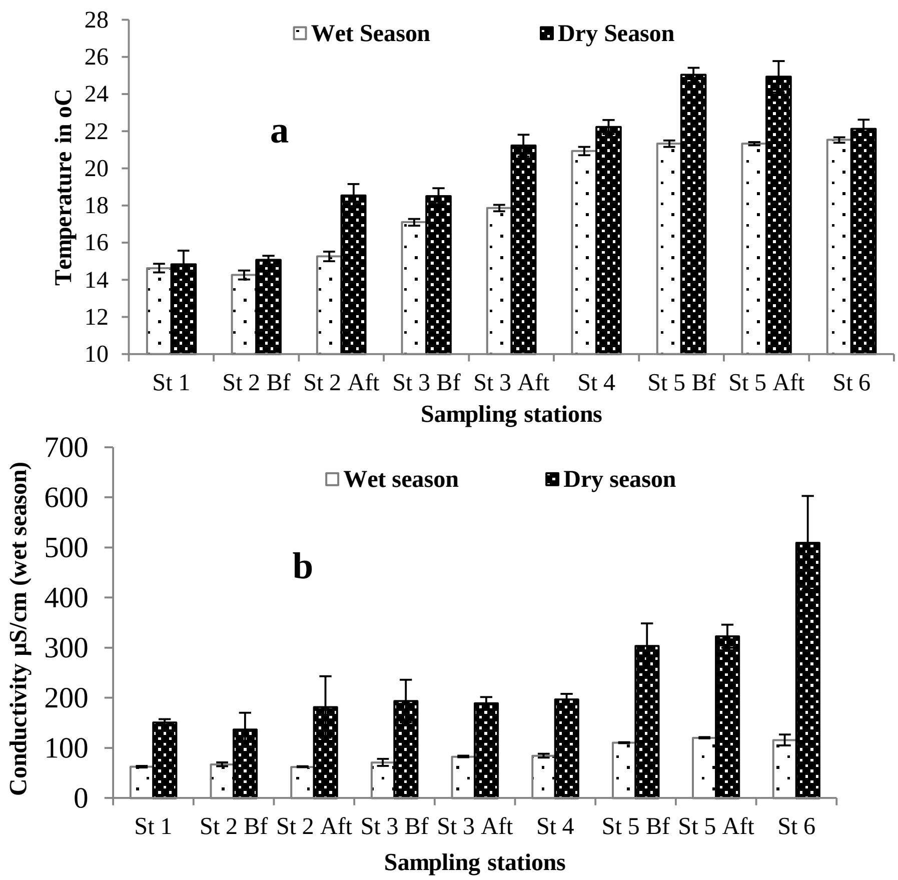

Figure 3: Mean Temperature (a) and Conductivity (b) measurements (± S. E) at River Sosiani during the study period.

Total organic nitrogen (TON) and total dissolved solids (TDS) also had an increasing trend as shown in Figure 4a and 4b respectively, with higher mean measurements during dry season compared to wet season. Total dissolved solids' mean measurement were presented in primary vertical axis for wet season and secondary vertical axis for the dry season mean measurements. It ranged between 40 g/l to 80 g/l in wet, and between 100 g/l to just above 300 g/l in dry season respectively.

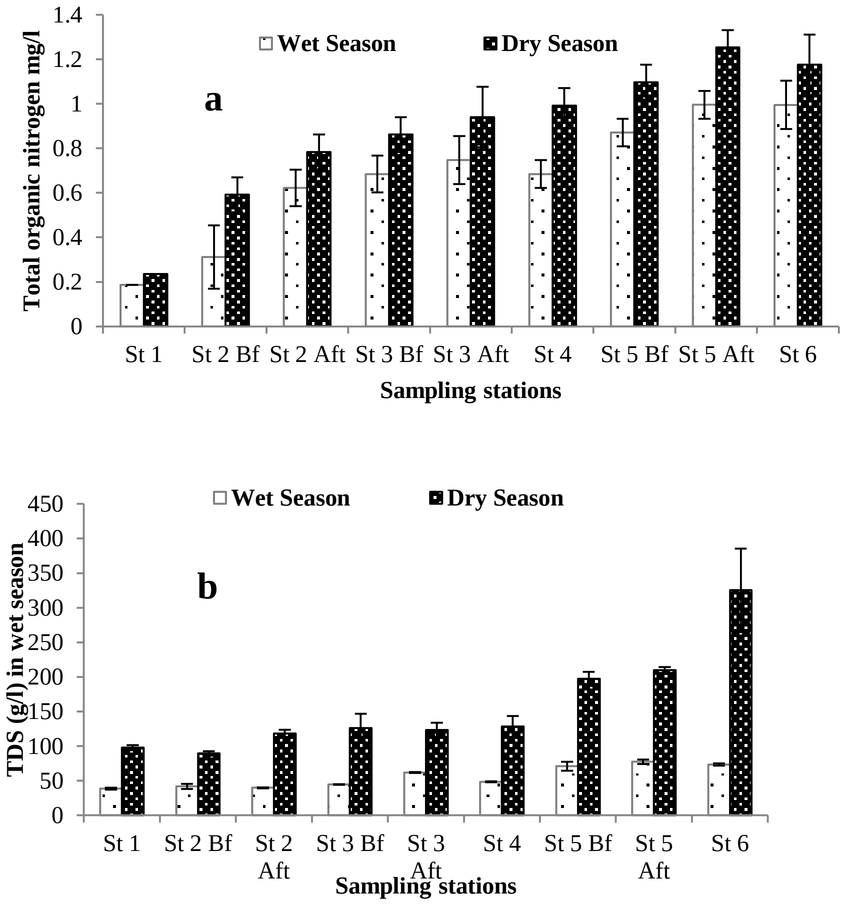

Figure 4: Mean TON (a) and TDS (b) measurements (± S. E) at River Sosiani during the study period.

Trend in BOD and DO were as presented in Figure 5a and 5b respectively. Biological oxygen demand had an increasing trend, though fluctuating; it had its peak at St 5 before Huruma sewage treatment ponds, followed by a decrease at the consequent sampling points. Mean measurement for DO was however the reverse of the above observations in that, it had a declining trend and, it was higher during the rainy season compared to the dry season. The dry season trend fluctuated, having low measurements after Elegrin Dam in St 2, after Two Rivers Dam in St 3, before Huruma sewage ponds at St 5 and at St 6.

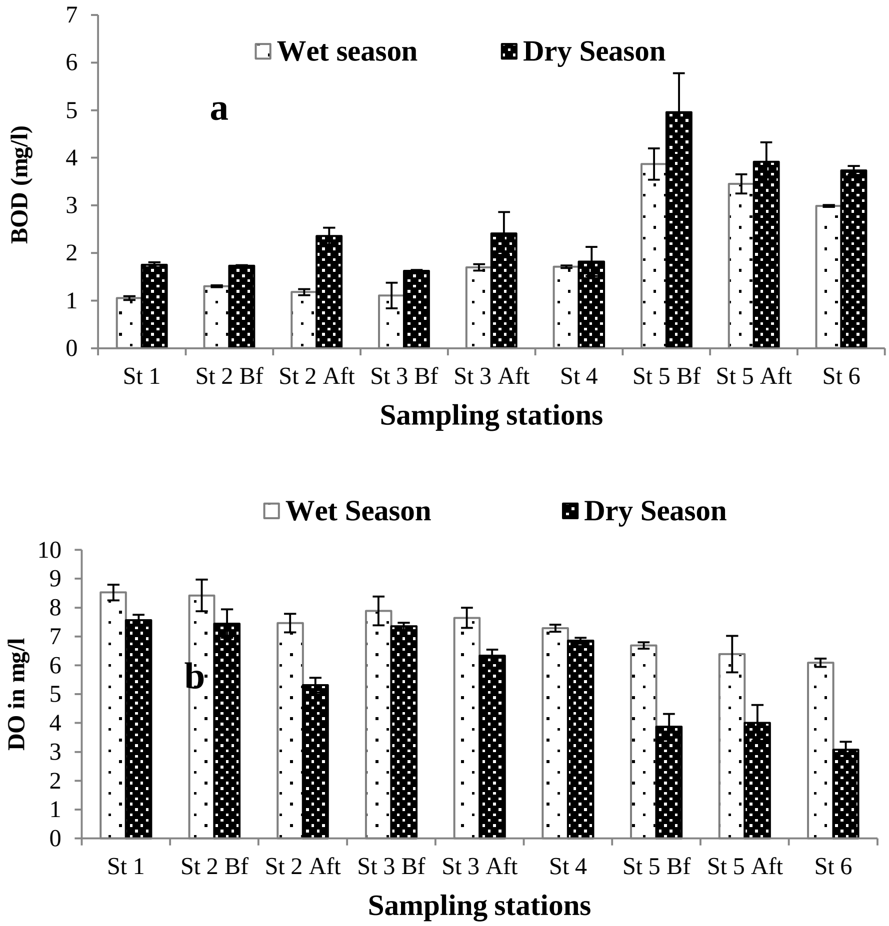

Figure 5: Mean BOD (a) and DO (b) measurements (±S. E) at River Sosiani during the study period.

Trend in TP and pH is shown in Figure 6a and 6b respectively. The mean TP was minimum at St 1 and fluctuated after Elegrin Dam in St 2 and Two Rivers Dam in St 3 and before Huruma sewage treatment ponds. It then dropped at the consecutive sampling points. The trend in mean pH measurement was unique. It was higher during the dry season than the wet season. Its trend during wet season declined though having some peaks after the Elegrin Dam at St 2 and after Huruma sewage treatment ponds at St 5. During the dry season, pH declined from St 1 to Elegrin Dam after St 2, it then rose to the peak at St 3 after Two Rivers Dam and then declined at the consequent stations.

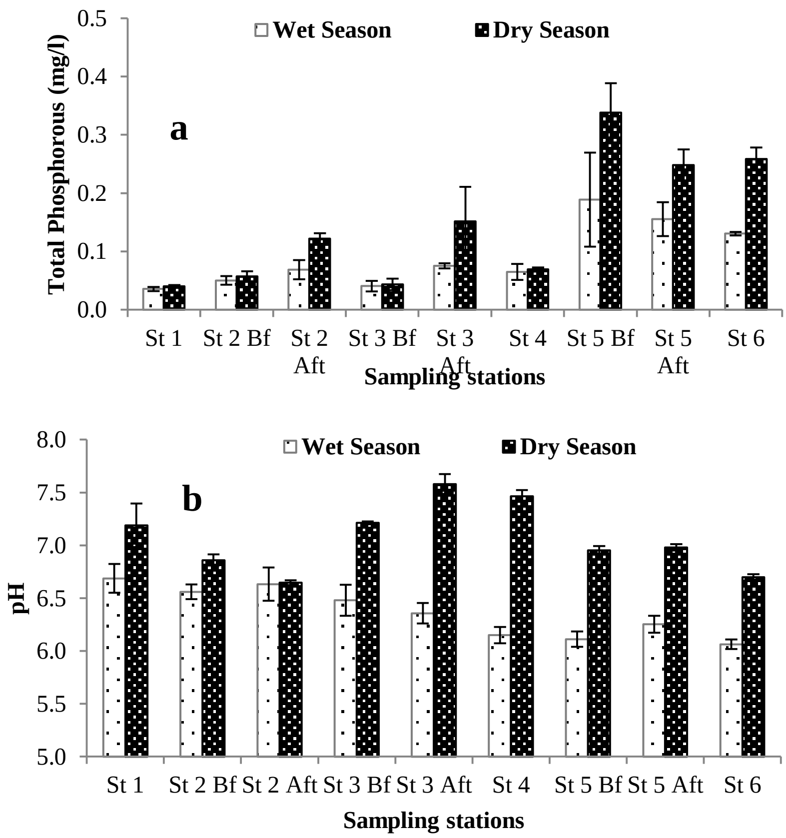

Figure 6: Mean TP (a) and pH (b) measurement (±S. E) at River Sosiani during the study period.

4.2.2. Temporal Variation in Water Quality

Spearman's *R* depicted a strong correlation between water quality parameters' measurement in wet and dry season (Table 6). Temperature (r = 0.862), TDS (r = 0.883), Conductivity (r = 0.900), DO (r = 0.933), BOD (r = 0.967), TP (r = 0.983), TON (r = 1.00). They all had p value $\leq$ 0.005, except for pH which had a weak correlation coefficient (*r* = -0.017) and a probability value (p = 0.948) which was not significantly different in both seasons.

Table 6: Temporal variation of water quality parameters at staions; Spearmans' R correlation and the p values.

W ≡ Wet Season, D ≡ Dry Season, *r* = Spearman's R and p = probability evaluation of hypothesis of no association at 95% cl

p \ r	Temp W	DO W	BOD W	TON W	TP W	Cond W	TDS W	pH W	Temp D	DO D	BOD D	TON D	TP D	Cond D	TDS D	pH D
Temp W		-0.93	0.78	0.92	0.80	0.90	0.90	-0.92	**0.86**	-0.86	0.76	0.92	0.82	0.98	0.98	-0.01
DO W	0.00		-0.80	-0.88	-0.85	-0.82	-0.85	0.85	-0.87	**0.93**	-0.73	-0.88	-0.87	-0.92	-0.92	0.28
BOD W	0.02	0.01		0.78	0.95	0.68	0.75	-0.65	0.83	-0.87	**0.97**	0.78	0.93	0.68	0.68	-0.22
TON W	0.00	0.00	0.02		0.85	0.92	0.98	-0.83	0.84	-0.85	0.77	**1.00**	0.84	0.91	0.91	0.01
TP W	0.01	0.01	0.00	0.01		0.73	0.83	-0.73	0.88	-0.92	0.92	0.85	**0.98**	0.72	0.72	-0.25
Cond W	0.00	0.01	0.05	0.00	0.03		0.97	-0.88	0.82	-0.68	0.72	0.92	0.72	**0.90**	0.90	0.12
TDS W	0.00	0.01	0.03	0.00	0.01	0.00		-0.87	0.83	-0.78	0.77	0.98	0.82	0.88	**0.88**	0.05
pH W	0.00	0.01	0.06	0.01	0.03	0.00	0.00		-0.83	0.77	-0.67	-0.83	-0.78	-0.88	-0.88	**-0.02**
Temp D	**0.01**	0.00	0.01	0.01	0.00	0.01	0.01	0.01		-0.80	0.87	0.84	0.85	0.82	0.82	0.02
DO D	0.01	**0.00**	0.00	0.01	0.00	0.05	0.01	0.02	0.01		-0.77	-0.85	-0.95	-0.82	-0.82	0.40
BOD D	0.02	0.03	**0.00**	0.02	0.00	0.03	0.02	0.05	0.00	0.02		0.77	0.88	0.65	0.65	0.02
TON D	0.00	0.00	0.02	**0.00**	0.01	0.00	0.00	0.01	0.01	0.01	0.02		0.84	0.91	0.91	0.01
TP D	0.01	0.00	0.00	0.01	**0.00**	0.03	0.01	0.01	0.01	0.00	0.00	0.01		0.73	0.73	-0.30
Cond D	0.00	0.00	0.05	0.00	0.03	**0.00**	0.00	0.00	0.01	0.01	0.06	0.00	0.03		1.00	-0.03
TDS D	0.00	0.00	0.05	0.00	0.03	0.00	**0.00**	0.00	0.01	0.01	0.06	0.00	0.03	0.00		-0.03
pH D	0.99	0.46	0.55	0.99	0.52	0.74	0.88	**0.95**	0.95	0.27	0.95	0.99	0.41	0.91	0.91	

4.2.3. Spatial Variation in Water Quality

Cluster analysis with Euclidean distance and wards standardization to compare the stations (similarity comparison) for the season is summarized in Figure 7. They were constrained to separate the stations in wet (ST_1…..) and dry (ST_1_D, ST_2_Bf_D…..) seasons. The most distant stations in similarity from all other stations were, ST 5 Bf D, ST 5 Aft D and Maili inne D (D≡ dry season) observed with Cluster 1 (C 1). Cluster 2 (C 2) separated the first four stations in wet season from the rest (ST 1, ST 2 Bf, ST 2 Aft, ST 3 Aft, ST 3 Bf and ST 4). The other clusters further divided them to the nearest similar stations (C 3, C 4, C 5 and C 6 respectively).

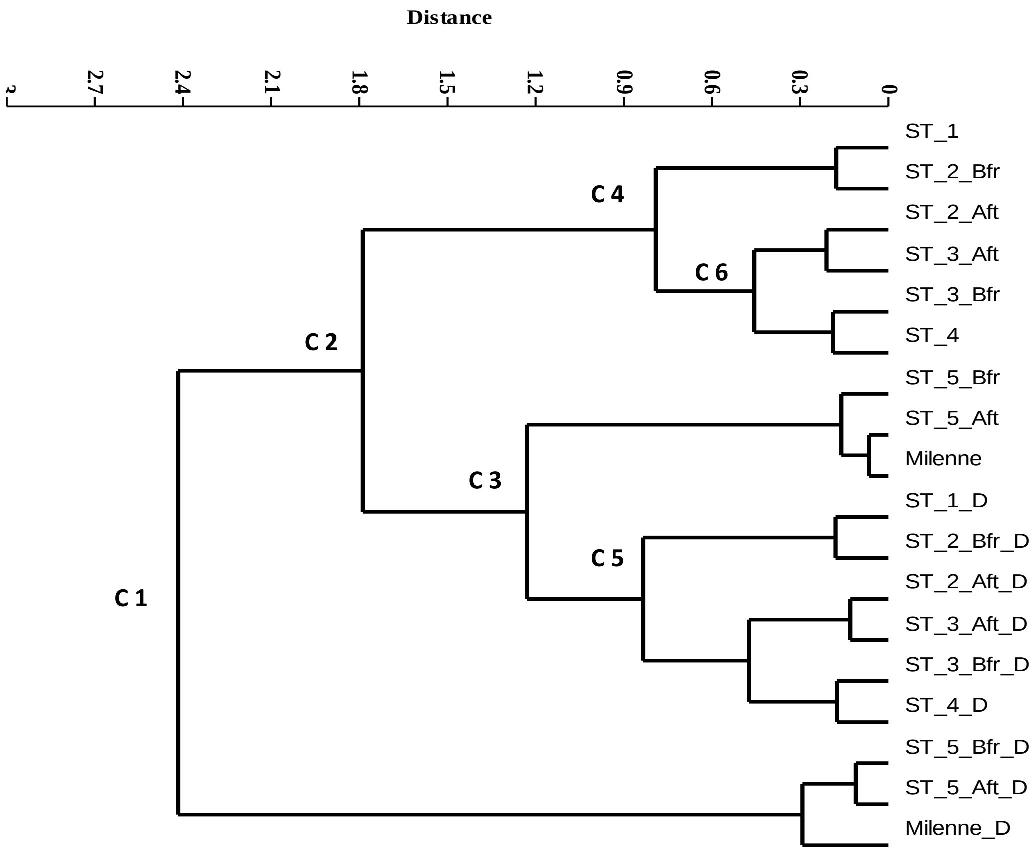

Figure 7: Dendrogram showing stations similar in water quality parameter measurements during the study period
D≡ dry season

Screen plot showing the number of significant components at 95% confidence interval is as in Figure 9. The first two components explained the variation in water quality parameters at the sampling stations in both seasons with component 1 explaining 60.5% variance and component 2 explaining 26.1 % of the variance.

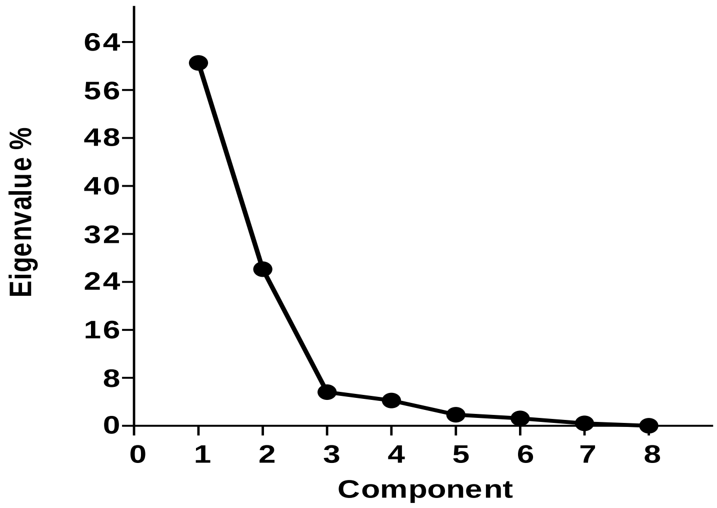

Figure 8: Screen plot of significant components with the measured water quality parameters

The results of the log transformed (normalized and standardize) 8 water quality parameters are shown in Figure 10. The first two significant components with PC 1 explaining 60.5 % of the total variance had a strong positive vector matrix with Temperature, TON, TP, Conductivity and TDS and, a negative vector matrix with DO. Principal component 2 explaining 26.1 % of the variance and had a strong positive vector matrix with pH and a negative vector matrix with BOD.

The pH was high at St 3 Bf and St 4 while Conductivity and TDS at St 3 Aft, St 5 Bf, St 5 Aft and St 6 during the dry seasons. Dissolved oxygen and BOD were more influential during the wet season. The DO was high at the upper catchment stations

(St 1, St 2 Bf and St 3 Bf) while BOD measurements were observed high at the lower altitude stations (St 5 Bf, St 5 Aft and St 6). Temperature, TON and TP were intermediate of the two seasons and the stations, but had much influence on St 5 Bf and Aft and also in St 6.

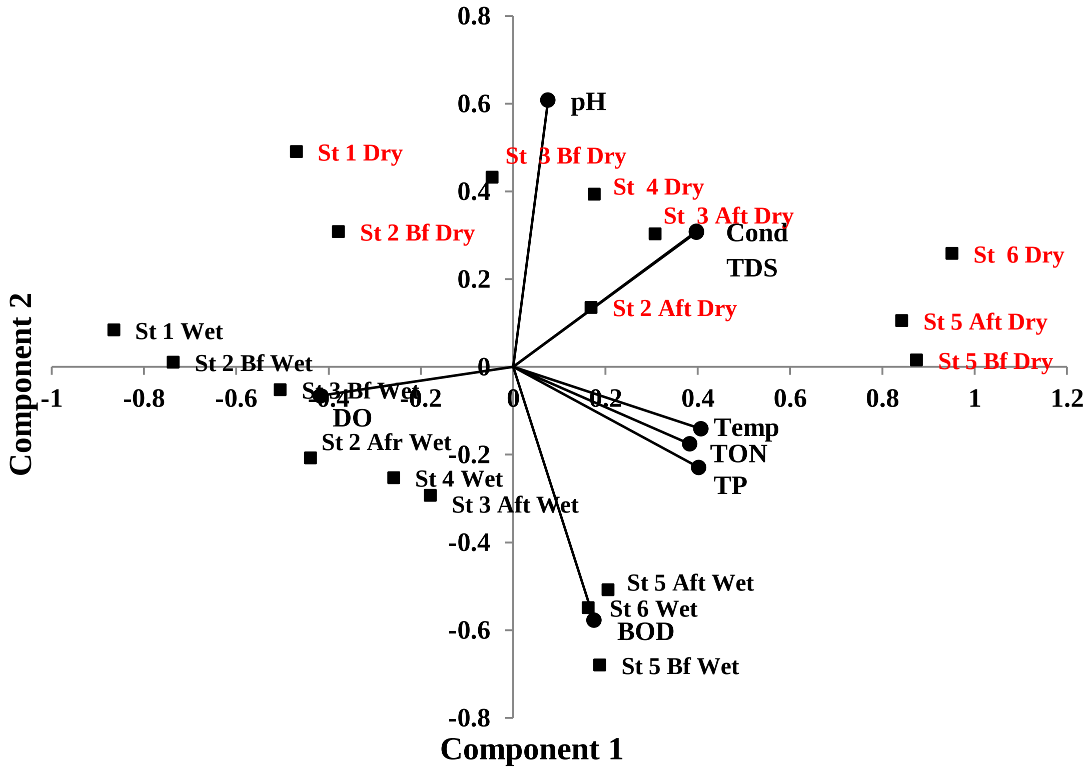

Figure 9: PCA of mean physico-chemical water quality parameters at the sampling sites during study period.

The intrinsic correlation of the water quality parameters with the stations is shown in Table 7. Varifactor 1 that explained 35.5% of the variance in wet season had positive factor loading of temperature (0.808) and conductivity (0.667), with a negative factor loading of pH (-0.875) while in dry season, and at 33.7 % variance, it had positive factor loading of conductivity (0.865) and TDS (0.861) and a negative factor loading of DO (-0.709). Varifactor 2 that explained 35.3 % of the variance in wet season had a negative factor loading of BOD (-0.878) and TP (-0.839) while in dry season and at 27.1% variance BOD had a negative loading (-0.915) and also for TP (-0.709). Finally, Varifactor 3 that explained 18.4% variance in wet season and 21.7 % variance in the dry season also had a strong negative factor loading of TON (Wet; -0.822, Dry; - 0.861) in both seasons.

Table 7: Factor analysis of physico-chemical water quality parameters at river Sosiani during study period

Rotated Factor Loadings Varimax Rotation					
Wet Season	**Variable**	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
	Temp	**0.808**	-0.339	-0.403	-0.139
	DO	-0.533	0.545	0.424	0.129
	BOD	0.339	**-0.878**	-0.208	-0.115
	TON	0.418	-0.348	**-0.822**	-0.118
	TP	0.319	**-0.839**	-0.396	-0.098
	Cond	**0.667**	-0.553	-0.256	-0.36
	TDS	0.549	-0.63	-0.307	-0.443
	pH	**-0.875**	0.334	0.31	0.083
	Variance	2.8414	2.8219	1.4735	0.4058
	% Var	**0.355**	**0.353**	**0.184**	0.051
Dry Season	**Variable**	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
	Temp	0.444	-0.562	-0.665	-0.144
	DO	**-0.709**	0.479	0.287	-0.409
	BOD	0.294	**-0.915**	-0.271	0.001
	TON	0.402	-0.305	**-0.861**	0.006
	TP	0.47	**-0.709**	-0.377	0.238
	Cond	**0.865**	-0.307	-0.351	0.186
	TDS	**0.861**	-0.312	-0.356	0.186
	Ph	-0.2	0.025	-0.042	**-0.978**
	Variance	2.6971	2.1707	1.7327	1.2718
	% Var	**0.337**	**0.271**	**0.217**	0.159

4.3. Vegetation along River Sosiani

4.3.1. Vegetation Classification

There were 263 plant species in 75 families identified and taxonomically classified at the six sampling stations along River Sosiani as summarized in Appendix 2. The largest family was Asteraceae with 39 species and dominated by *Crassocephalumspp, Coniza spp* and *Vernonia spp.* All species in this family were of indigenous status except *Guizortia scabra,* which was exotic. Family Poaceae was the second in abundance (23 species), with *Brachiaria spp, Chloris spp, Digitaria spp, Eragrostis spp, Hyparrhenias spp* and *Panicum spp,* being dominant. Except for *Zea mays,* the rest of the species were of indigenous status. Family Cyperaceae and Limnaceae had 11 species identified in each of them; dominated by *Cyperus spp* for family Cyperaceae and *Plectranthus spp* for Limnaceae. All species in both families were of indigenous status. Family Pappilionaceae had 10 species, dominated by *Trifolium spp*. Family Euphorbiaceae and Solanaceae had 9 species each, dominated by *Croton spp* for the former and *Solanum spp* for the latter.

All species in Euphorbiaceae were indigenous in status while *Lupinus princei* was an exotic species in the family Pappilionaceae and similarly, *Physalis peruviana* in family Solanaceae. Family Rubiaceae had 8 species and was dominated by *Vangueria spp*, all were of indigenousstatus. Family Rosaceae and Mimosaceae had 7 species each, with the former being dominated by *Alchemilla spp* and *Rubus spp,* with *Eriobotrya japonica* being exotic in this family. The latter family dominated by *Acacia spp,* and had two exotic species *Acacia mearnsii* and *Acacia melanoxylon*. Commelinaceae and Polygonaceae had 6 species each while Malvaceae had 5 species. None of these last mentioned families had an exotic species; however, *Commelina spp* was dominant for the first family, *Polygonum spp* being dominant in family

Polygonaceae and *Sida spp* being dominant in family Malvaceae. The rest were either 4 species per family or less, with a few being exotic.

Table 8 show the 15 families and 17 species that were identified as exotic. Most of these exotic species were found in St 4 (11 species), followed by St 1 with five species. Station 5 and St 6 had three species found in each of them while St 3 had two species. Station 2 did not have any exotic species during the sampling period.

Table 8: Exotic vegetation identified in River Sosiani during the sampling period.

Family	Species	St 1	St 2	St 3	St 4	St 5	St 6
Amaranthaceae	*Amaranthus spinosa*	-	-	-	-	-	√
Asteraceae	*Guizortia scabra*	-	-	-	-	-	√
Poaceae	*Zea mays*	-	-	√	√	-	-
Caesalpiniaceae	*Acrocarpus fraxinifolius*	-	-	-	√	-	-
Casuarinaceae	*Casuarina equisetifolia*	-	-	-	-	√	-
Cupressaceae	*Cupressus lusitanica*	√	-	-	√	-	-
Mimosaceae	*Acacia mearnsii*	-	-	-	√	-	-
	Acacia melanoxylon	√	-	-	√	-	-
Myrtaceae	*Eucalyptus saligna*	√	-	-	√	-	√
Pappilionaceae	*Lupinus prince*	-	-	√	-	-	-
Phyllanthaceae	*Bischofia javanica*	-	-	-	√	-	-
Phytolacaceae	*Phytolacca octandra*	-	-	-	-	√	-
Pinaceae	*Pinus patula*	√	-	-	√	-	-
	Pinus radiate	√	-	-	-	-	-
Proteaceae	*Grevillea robusta*	-	-	-	√	√	-
Rosaceae	*Eriobotrya japonica*	-	-	-	√	-	-
Solanaceae	*Physalis peruviana*	-	-	-	√	-	-

The vegetation was further grouped into 18 habits (Figure 11). Erect herb, Tree, Shrub, Grass, Climber, Sedge, Creeper, Succulent herb, Floating rooted herb, Dwarf shrub, Prostrate herb, Liverwort, Liana, Reed, Rhizomatous herb, Submerged herb, Parasite and Free floating herb; in descending order of their abundance for the first 11 habits along the horizontal axis. Erect herb were more in St 4 and St 5 followed by St 6 then St 3, habit tree were more in St 4 followed by St 1 then St 5 and St 6.

Though St 1 and St 5 dominated with shrub, they were relatively plentiful in all the stations. Habit grass was dominant in St 3, St 4 and St 5, climber; St 6, sedge; St 3 and Creeper in St 5. Other plant habits were relatively less abundant and found in a few stations. The reference site (St 1) however had about all these habits.

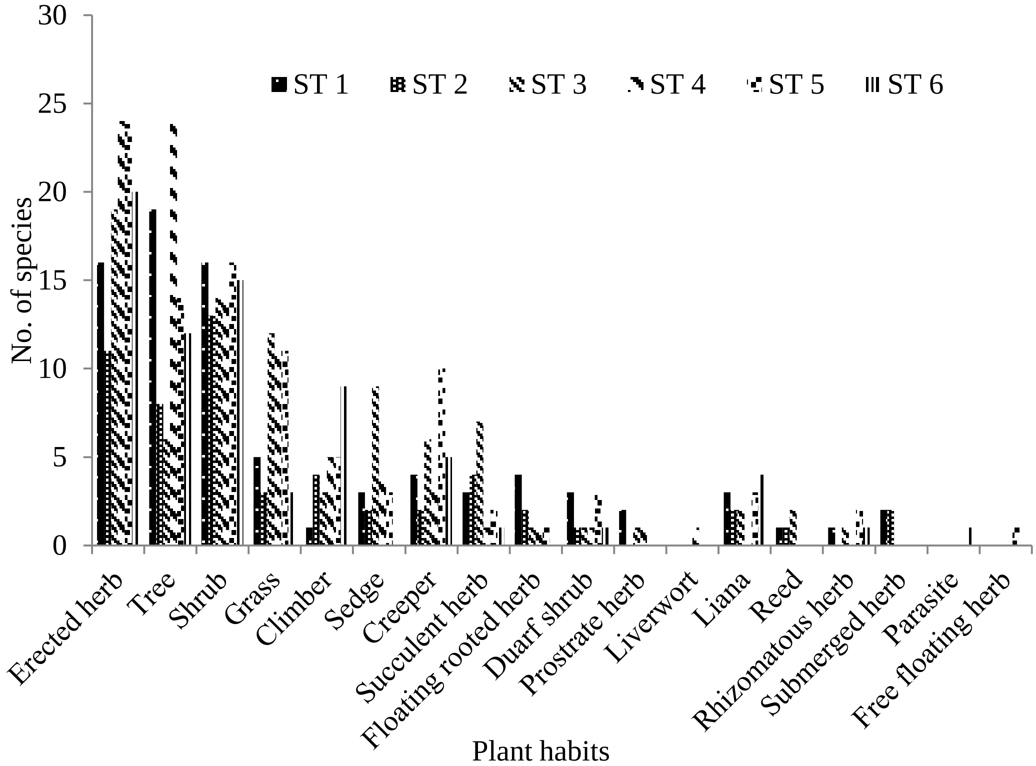

Figure 10: Vegetation habits along River Sosiani during the study period

Plant species at the riparian and riverine wetland zone were also grouped into either aquatic, semi aquatic or riverine (Figure 12). All of the five stations had aquatic vegetation, they were however dominant in St 1, followed by St 2 , St 3 and St 5, with relatively equal number of species, while St 4 and St 6 had the least aquatic vegetation, respectively. Semi-aquatic vegetation were however plenty in St 3 followed by St 5 then St 2 and St 4 and lastly, St 1 and St 6. Station 1 dominated with the riverine species followed by St 2 and St 3 (Two Rivers Dam) respectively. Station 5 (Huruma) also had some few species of riverine habitat while St 4 and St 6 (Maili inne) had none.

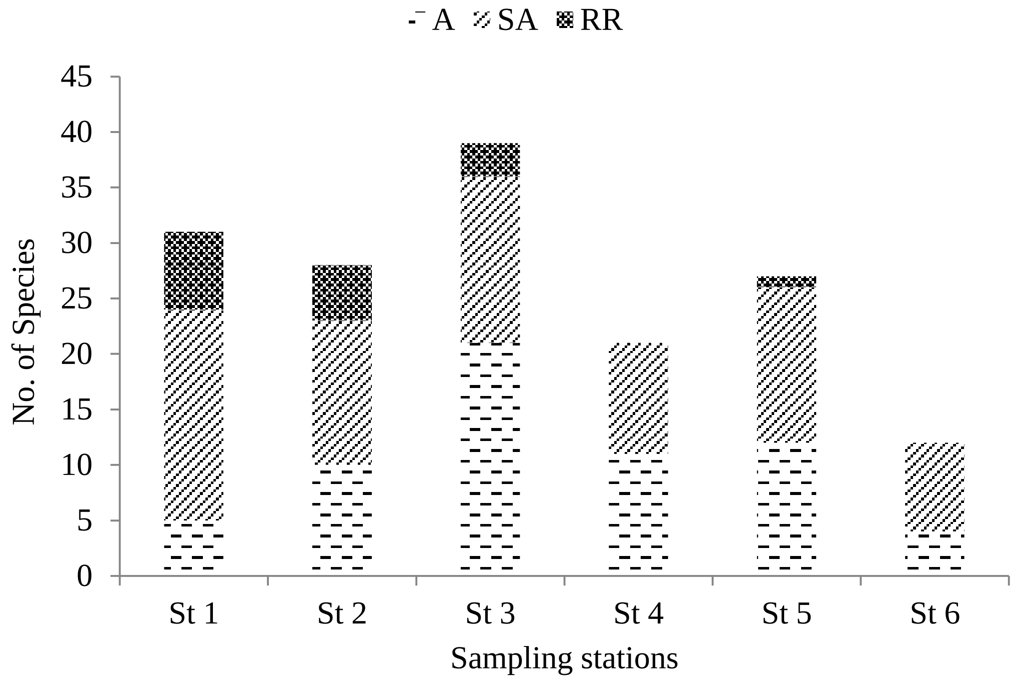

Figure 11: Changes in Aquatic, Semi-aquatic and Riverine plant species along River Sosiani during the study period.

4.3.2. Macrophytes of River Sosiani

Macrophytes of Sosiani River were classified as shown in Table 9. Twenty families with 41 species were identified during the sampling period. All of the classified species were of indigenous origin and, most of them belonged to family Cyperaceae (9 species), followed by Poaceae and Polygonaceae; with four species each, and Onagraceae with three species. Apiaceae, Asteraceae, Commelinaceae and Typhaceae had two species each.

Table 9: Macrophytes of River Sosiani during the study period

FAMILY	SPECIES
Acanthaceae	*Hygrophylla auriculata*
Apiaceae	*Peucedanum aculeolatum*
	Hydrocotyle sibthorpioides
Asteraceae	*Hoehneria vernonioides*
	Sphaeranthus suaveolens
Chlorophyceae	*Elodea Canadensis*
Commelinaceae	*Floscopa glomerata*
	Murdannia simplex
Crasulaceae	*Crassula gravinkii*
Cyperaceae	*Cyperus alternifolius*
	Cyperus laevigatus
	Cyperus rigidifolius
	Cyperus strigosum
	Eleocharis radicans
	Fimbristylis complanata
	Fuirena stricta
	Pycreus nitidus
	Schoenoplectus corymbosus
Lemnaceae	*Lemna gibba*
Lythraceae	*Rotala tenella*
Marantaceae	*Maranta arundinacea*
Marchantiaceae	*Marchantia polymorpha*
Nymphaeaceae	*Nymphaea lotus*
Onagraceae	*Epilobium hirsutum*
	Ludwigia abyssinica
	Ludwigia leptocarpa
Pappilionaceae	*Aeschenomene abyssinica*
Poaceae	*Echinochloa pyramidalis*
	Eragrostis chalarothyrsus
	Leersia hexandra
	Panicum hymeniochilum
Polygonaceae	*Polygonum pulchrum*
	Polygonum salicifolia
	Polygonum setosulum
	Polygonum strigosum
Potamogetonaceae	*Potamogeton schweinfurthii*
	Aponogeton stulmanii
Ranunculaceae	*Ranunculus multifidus*
Typhaceae	*Typha domingensis*
	Typha latifolia
Zygnemataceae	*Spyrogyra*

4.3.3. Aquatic, Semi-aquatic and Riverine vegetation with TON and TP gradient

The abundance and sensitivity of the aquatic, semi-aquatic and riverine vegetation was evaluated with TON and TP gradient at the stations as shown in Figure 13. Aquatic vegetation were abundant between 0.8 and 0.9 mg/l TON and 0.12-0.15 mg/l

TP (Figure 13a), the semi-aquatic vegetation; 0.7-0.8 mg/l TON and 0.12-0.15 mg/l TP (Figure 13b) and the riverine species; ≈ 0.5 mg/l TON and 0.06-0.09 mg/l TP (Figure 13c).

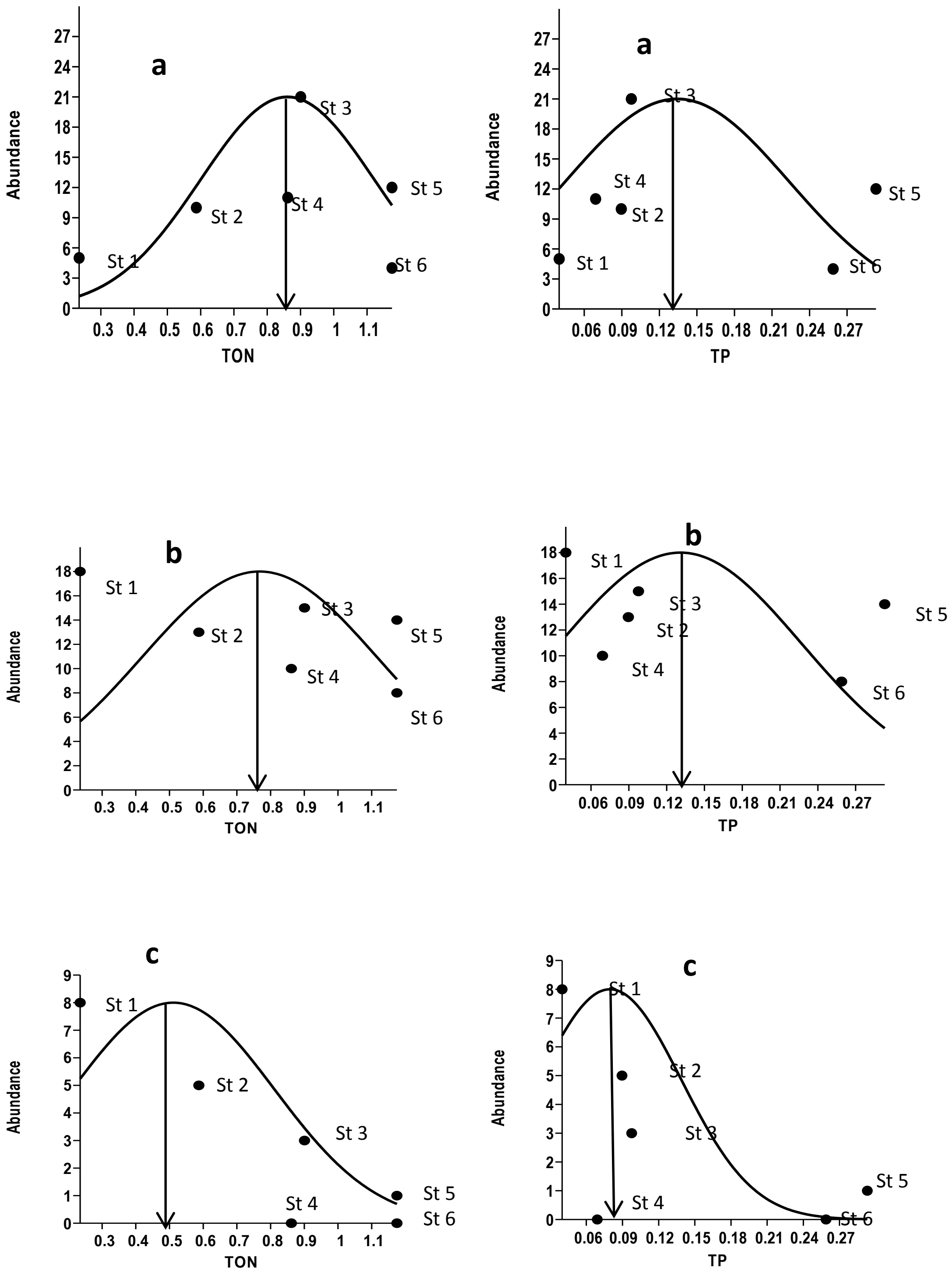

Figure 12: Abundance of aquatic (a), semi-aquatic (b) and riverine (c) vegetation with TON and TP concentrations (mg/l) during the sampling period.

Riverine vegetation was more abundant at the upper catchment stations (Table 10). *Acacia abyssinica*, *Acacia xanthophloea, Cordia abyssinica, Ficus thonningii and Phoenix reclinata* at St 1 and St 2 while, *Albizia gummifera* and *Sizygium guineensis* were sampled at St 1 and St 3. Only one species was found at St 5 (*Sizygium cordatum).* The semi-aquatic species were found in two stations or more; *Trifolium lugardii* in St 1 and 6, *Gomphocarpus physocarpus* in St 1, St 2 and St 3, *Craterostigma pumilum* in St 1, St 2, St 3 and St 5 and *Crassocephalum montuosum* in St 1, St 2, St 3, St 5 and St 6.

Table 10: Semi-aquatic and riverine plantspecies sampled at River Sosiani during the study period

Species	Habitat	St 1	St 2	St 3	St 4	St 5	St 6
Acacia abyssinica	***RR***	√	√	-	-	-	-
Acacia xanthophloea	***RR***	√	√	-	-	-	-
Acmella calirhiza	SA	√	√	-	√	√	√
Aeolanthus heliotropoides	SA	√	√	-	√	-	-
Albizia gummifera	***RR***	√	-	√	-	-	-
Aspilia mossambiscensis	SA	√	√	√	√	√	-
Centella asiatica	SA	√	-	-	-	√	√
Commelina Aftricana	SA	√	√	√	-	√	-
Cordia abyssinica	***RR***	√	√	-	-	-	-
Crassocephalum montuosum	SA	√	√	√	-	√	√
Crassocephalum picridifolium	SA	√	-	√	√	√	-
Craterostigma pumilum	SA	√	√	√	-	√	-
Cyanotis foecunda	SA	√	-	√	√	-	-
Cyphostemma adenocaule	SA	√	√	√	-	√	-
Dipsacus pinnatifidus	SA	√	√	√	√	-	-
Ficus thonningii	***RR***	√	√	-	-	-	-
Galium scioanum	SA	√	√	√	√	√	-
Gomphocarpus physocarpus	SA	√	√	√	-	-	-
Kyllinga bulbosa	SA	√	-	√	-	√	-
Phoenix reclinata	***RR***	√	√	-	-	-	-
Plectranthus edulis	SA	√	-	-	-	-	√
Rumex bequaertii	SA	√	√	√	-	√	√
Sesbania sesban	SA	-	√	√	√	√	√
Sizygium cordatum	***RR***	√	-	√	-	√	-
Sizygium guineensis	***RR***	√	-	√	-	-	-
Torilis arvensis	SA	√	-	√	√	√	-
Trifolium lugardii	SA	√	-	-	-	-	√
Verbena bonariensis	SA	-	√	√	√	√	√

Emergent macrophytes were abundant at 0.8-0.9 mg/l TON, 0.12-0.15 TP (Figure 14a), while the rooted floating, and submerged macrophytes were abundant at 0.9-1.0 mg/l TON and 0.12-0.15 mg/l TP (Figure 14b and 14c).

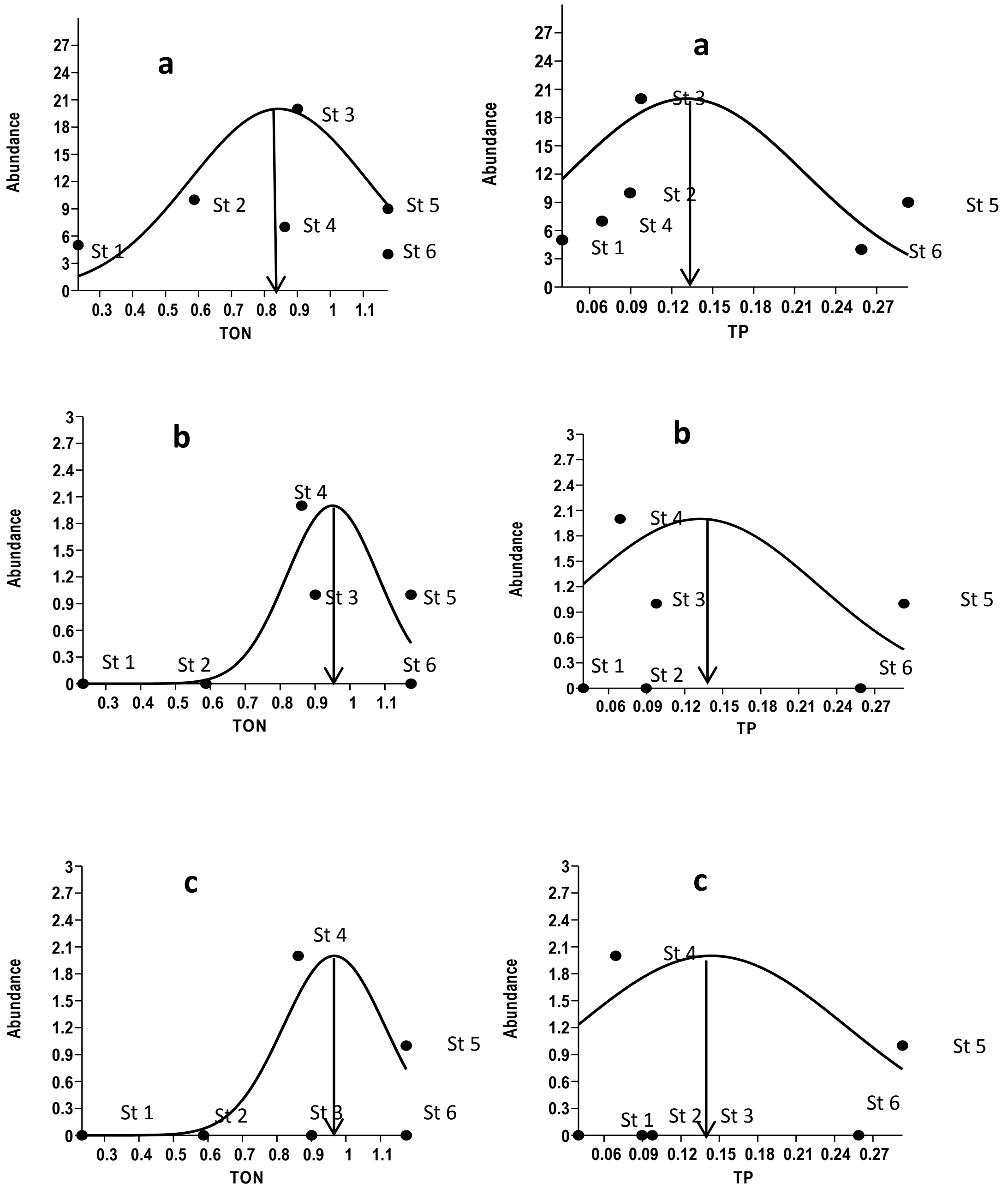

Figure 13: Abundance of emergent (a), rooted floating (b) and submerged (c) macrophytes with TON and TP concentrations (mg/l) during the sampling period

Macrophytes found in each station are summarized in Table 11. There were four species found only in St 1; *Polygonum pulchrum*, *Polygonum strigosum, Pycreus nitidus* and *Schoenoplectus corymbosus*, all were emergent. Three species found only at St 2; *Aeschenomene abyssinica*, *Fimbristylis complanata, Fuirena stricta*, these too were emergent. Eight species found only at St 3 (nutrient rich); C*yperus laevigatus. Cyperus strigosum, Maranta arundinacea, Marchantia polymorpha, Murdannia simplex*, *Polygonum setosulum*, *Typha latifolia* (emergent) and *Hydrocotyle sibthorpioides* (rooted floating). Three species in St 4; *Aponogeton stulmanii* (rooted floating), *Sphaeranthus suaveolens*, (emergent) and *Spyrogyra spp* (submerged) while St 5 had two species; *Lemna gibba* (free floating) and *Ludwigia abyssinica* (emergent) and St 6 had one species; *Floscopa glomerata* (emergent) uniquely identified in it (municipal waste). The rest of the species were found in either two or three of the stations.

Table 11: Macrophyte species sampled at River Sosiani during the study period.

Species	Category	**St 1**	**St 2**	**St 3**	**St 4**	**St 5**	**St 6**
Aeschenomene abyssinica	**Emergent**	-	√	-	-	-	-
Aponogeton stulmanii	**Rooted floating**	-	-	-	√	-	-
Crassula gravinkii	**Emergent**	-	√	-	-	-	√
Cyperus alternifolius	**Emergent**	-	√	√	-	-	-
Cyperus laevigatus	**Emergent**	-	-	√	-	-	-
Cyperus rigidifolius	**Emergent**	√	√	√	-	-	-
Cyperus strigosum	**Emergent**	-	-	√	-	-	
Echinochloa pyramidalis	**Emergent**	-	-	√	-	√	-
Eleocharis radicans	**Emergent**	-	-	√	-	√	-
Elodea Canadensis	**Submerged**	-	-	-	√	√	-
Epilobium hirsutum	**Emergent**	-	√	√	-	√	-
Eragrostis chalarothyrsus	**Emergent**	-	√	-	-	√	-
Fimbristylis complanata	**Emergent**	-	√	-	-	-	-
Floscopa glomerata	**Emergent**	-	-	-	-	-	√
Fuirena stricta	**Emergent**	-	√	-	-	-	-
Hoehneria vernonioides	**Emergent**	-	-	-	√	-	√
Hydrocotyle sibthorpioides	**Rooted floating**	-	-	√	-	-	-
Hygrophylla auriculata	**Emergent**	-	-	√	-	√	-
Leersia hexandra	**Emergent**	-	-	-	-	√	√
Lemna gibba	**Free floating**	-	-	-	-	√	-
Ludwigia abyssinica	**Emergent**	-	-	-	-	√	-
Ludwigia leptocarpa	**Emergent**	-	-	√	-	√	-
Maranta arundinacea	**Emergent**	-	-	√	-	-	-
Marchantia polymorpha	**Emergent**	-	-	√	-	-	-
Murdannia simplex	**Emergent**	-	-	√	-	-	-
Nymphaea lotus	**Rooted floating**	-	-	-	√	√	-
Panicum hymeniochilum	**Emergent**	-	-	√	√	-	-
Peucedanum aculeolatum	**Emergent**	-	√	√	-	-	-
Polygonum pulchrum	**Emergent**	√	-	-	-	-	-
Polygonum salicifolia	**Emergent**	-	-	√	√	-	-
Polygonum setosulum	**Emergent**	-	-	√	-	-	-
Polygonum strigosum	**Emergent**	√	-	-	-	-	-
Potamogeton schweinfurthii	**Emergent**	-	-	-	√	√	-
Pycreus nitidus	**Emergent**	√	-	-	-	-	-
Ranunculus multifidus	**Emergent**	-	√	√	-	-	-
Rotala tenella	**Emergent**	-	-	√	√	-	-
Schoenoplectus corymbosus	**Emergent**	√	-	-	-	-	-
Sphaeranthus suaveolens	**Emergent**	-	-	-	√	-	-
Spyrogyra	**Submerged**	-	-	-	√	-	-
Typha domingensis	**Emergent**	-	-	√	√	-	-
Typha latifolia	**Emergent**	-	-	√	-	-	-

Summary of the vegetation classification at the six stations along River Sosiani were then grouped according to their frequency in different taxa/categories as in Table 12. Species richness was high in St 4 and St 5 (90 and 95 respectively), this too was observed with genera (84 and 82 respectively) and similarly, with the families (40 and 43 respectively), except for St 1 which also had 40 families. Most of the terrestrial plant species were observed in St 4 and St 5 (69 and 92 respectively). However, the semi-aquatic species dominated St 1, St 2, St 3 and St 5 (18, 13, 15 and 14 respectively). The aquatic species were dominant in St 3 (21 species) while the riverine vegetation were abundant in St 1 and St 2. Most of the exotic plants were in St 4 and none of these exotic species was observed in St 2. The indigenous vegetation was abundant in St 1, St 3, St 4 and St 5 (78, 82, 79 and 92 respectively).

All of the stations had relatively plentiful plant habits, St 3 and St 5 however dominated with 15 and 16 plant habits respectively. Emergent macrophytes were observed more in St 3 (20 species) followed by St 2 with ten species. The rooted floating macrophytes were few in number and only present in St 3, St 4 and St 5, free floating macrophyte being observed in St 5 while submerged macrophytes were in St 4 and St 5.

In total, there were 263 species, 207 genera, 75 families, 194 terrestrial, 20 semi aquatic, 41 aquatic, 8 riverine, 17 exotic, 246 indigenous, 18 habits, 35 emergent, 3 rooted floating, 1 free floating and 2 submerged vegetation that were identified along River Sosiani during the sampling period.

Table 12: Frequency of vegetation classification along River Sosiani during the sampling period.

Stations	Species	Genera	Families	Terrestrial	Semi aquatic	Aquatic	Riverine
St 1	83	69	**40**	52	**18**	5	**8**
St 2	55	53	32	27	**13**	10	**5**
St 3	84	74	38	45	**15**	**21**	3
St 4	**90**	**84**	**40**	**69**	10	11	0
St 5	**95**	**82**	**43**	**92**	**14**	12	1
St 6	72	67	30	60	8	4	0
Sosiani	**263**	**207**	**75**	**194**	**20**	**41**	**8**
Stations	**Exotic**	**Indigenous**	**Habit**	**Emergent**	**Rooted floating**	**Free floating**	**Submergent**
St 1	5	**78**	13	5	0	0	0
St 2	0	55	11	10	0	0	0
St 3	2	**82**	**15**	**20**	1	0	0
St 4	**11**	**79**	13	7	**2**	0	**2**
St 5	3	**92**	**16**	9	1	1	1
St 6	3	69	14	4	0	0	0
Sosiani	**17**	**246**	**18**	**35**	**3**	**1**	**2**

Simpson diversity, evenness and dominance of the genera were then generated as plotted in Figure 15. In general, the entire sampling area had high diversity and low Evenness (primary vertical axis), with low dominance (secondary vertical axis). The diversity gradually decreased while evenness and dominance increased to St 2, followed by slight increase in diversity and decline in dominance and evenness at St 3. Dominance however decline to St 4 and increased up to the last station. Evenness changed from high in St 4 to low in St 5 and finally high in St 6.

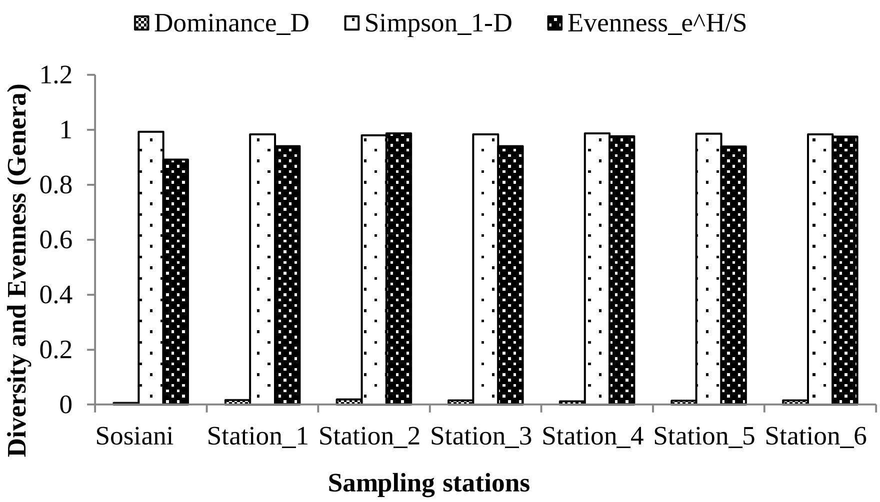

Figure 14: Variation in Diversity, Evenness and Dominance of vegetation along River Sosiani during the study period.

4.4. Composition, Abundance and Diversity of Macroinvetebrates along River Sosiani

This study identified 9 orders and 29 families of macroinvertebrates (Table 13). The orders include, Coleoptera, Decapoda, Diptera, Ephemeroptera, Hemiptera, Lepidoptera, Odonata, Trichoptera and Veneroidea. Ephemeroptera was the most abundant with seven families namely Baetidae, Baetisidae, Caenidae, Ephemerellidae, Ephemeralidae, Heptageniidae and Siphlonuridae, followed by Trichopteridae with six families; Caddysfly, Ecnomidae, Hydropsichidae, Lepidostomatidae, Leptoceridae and Policentropodidae. Odonata had four families and, Coleoptera, Diptera and Hemiptera had 3 families each. The rest had two or one family in each order. Some families were found at specific stations like Ephemerellidae, Gomphidae and Caddysfly were only observed in St 1, while Baetidae and Hydropsichydae were abundant in St 2, St 3 and St 5.

Table 13: Orders and families of macroinvertebrate at River Sosiani during the sampling perid

< 20≡ *, 21—50 ≡ **, 51—100≡ *** and > 100 ≡ ****

Order	Family	St 1	St 2 Bf	St 2 Aft	St 3 Bf	St 3 Aft	St 4	St 5 Bf	St 5 Aft	St 6
Coleoptera	Corixidae	-	-	-	-	-	-	*	-	-
	Gyrinidae	**	-	**	*	*	**	*	*	-
	Scirtidae	-	-	*	-	-	-	*	-	-
Decapoda	Potamonautidae	*	*	*			-	*	-	-
Diptera	Chironomidae	**	-	**	-	**	-	*	**	**
	Muscidae	-	-	-	-	-	-	*	-	*
	Simuliidae	-	-	***	-	*	*	*	**	**
Ephemeroptera	Baetidae	-	*	*	-	*	**	**	***	**
	Baetisidae	-	-	-	-	*	-	-	-	-
	Caenidae	-	-	-	-	-	**	*	-	*
	Ephemerellidae	**	-	-	-	-	-	-	-	-
	Ephemeralidae	-	*	-	*	-	-	-	-	-
	Heptageniidae	-	*	-	-	-	-	-	-	*
	Siphlonuridae	-	-	-	-	-	-	****	-	-
Hemiptera	Gerridae	**	-	**	*	-	*	-	-	-
	Neucoridae	-	-	*	-	**	*	*	-	-
	Gerridae	-	-	-	*	-	-	-	-	-
Lepidoptera	Crambidae	-	-	*	-	-		*	-	-
Odonata	Aeshinidae	*	-	**	-	-	*	*	-	-
	Gomphidae	*	-	-	-	-	-	-	-	-
	Lestidae	-	-	-	-	*	**	*	-	-
	Libellulidae	-	-	-	-	-	*	-	-	-
Trichoptera	Caddisfly	*	-	-	-	-	-	-	-	-
	Ecnomidae	-	-	-	**	-	-	-	-	-
	Hydropsychidae	-	-	**	*	***	*	*	**	**
	Lepidostomatidae	-	*	-	-	-	-	-	-	***
	Leptoceridae	-	-	*	-	-	*	-	-	-
	Polycentropodidae	-	-	-	-	-	*	-	-	-
Veneroidea	Sphaeriidae	**	-	*	-	-	-	**	*	-

The percentage relative abundance of the orders is presented in Figure 16. Except for order Lepidoptera, all other orders were found in St 1, with orders Coleoptera, Diptera, Hemiptera and Veneroidea being relatively abundant at the station. Station 2 Bf had only three orders, with Decapoda and Ephemeroptera dominating the group but with a few of Trichoptera. Station 2 Aft had all the orders present though, Diptera dominated the group. Station 3 Bf had four orders; dominated by Trichoptera. Station 3 Aft was also dominated by Trichoptera, and St 4 by Coleoptera and Ephemeroptera, St 5 Bf was dominated by Ephemeroptera, six orders were in these three sampling points. Diptera and Ephemeroptera dominated St 5 Aft while St 6 had abundant of Diptera and Trichoptera.

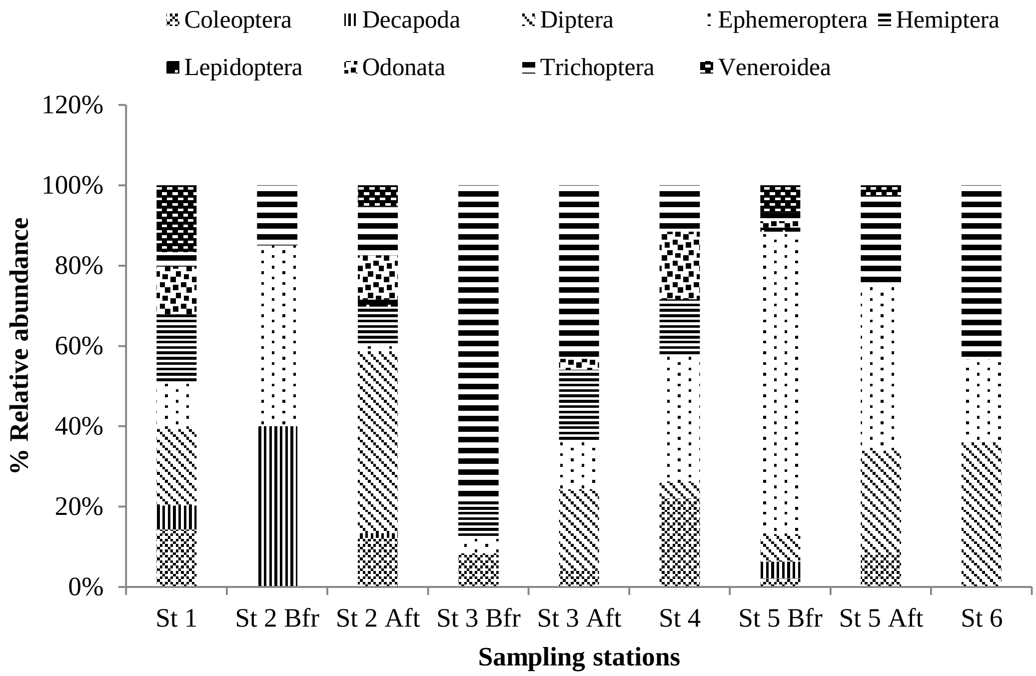

Figure 15: Percentage relative abundance of macroinvertebrate orders at River Sosiani during the sampling period.

Simpson diversity, evenness and dominance of the families is presented in Figure 17. The diversity fluctuated from low to high in St 1 and 2 and this pattern was repeated up to St 6. Evenness was highest in St 1 and dropped up to St 3, it then rose at St 4 and dropped at St 5 followed by final rise at St 6. Dominance was minimum at St 1, higher at St 2 followed by a further increase at St 3, a drop was observed at St 4, increase at St 5 and dropped at St 6.

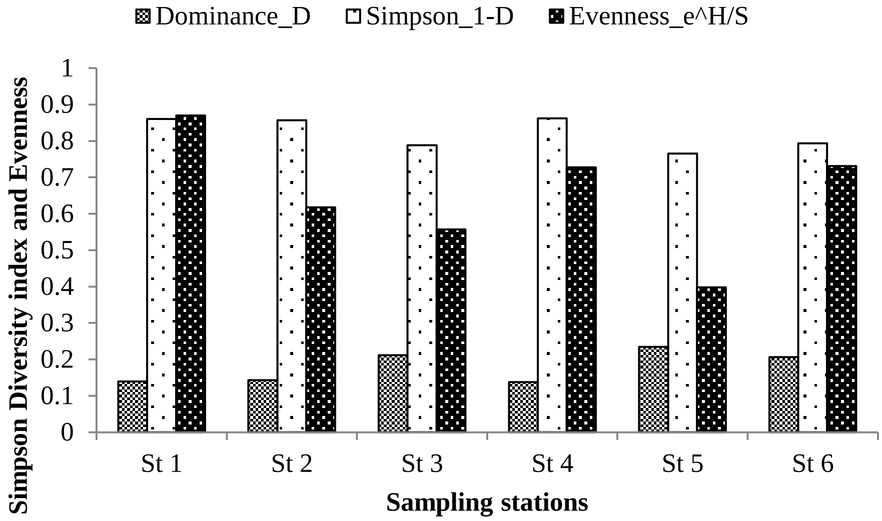

Figure 16: Simpson diversity, Evenness, and dominance of macroinvertebrates at River Sosiani during the sampling period.

The optimum concentration and tolerance of macroinvertebrate families were evaluated with TON, TP and BOD (mg/l) as shown in Table 14. Family Corixidae, Baetisidae, Siphlonuridae, Gerridae, Libellulidae, Caddisfly, Ecnomidae and Polycentropodidae were similar in their tolerance level to these three water quality parameters (0.01 mg/l). They however differed in their optimum concentration for each of the three parameters. In addition to the above families, Muscidae, Caenidae, Ephemerellidae, Neucoridae, Gomphidae, Lestidae and Leptoceridae had less than 0.1 mg/l level of tolerance to TON concentration, while the tolerance level for family Ephemeralidae was also less than 0.1 mg/l to BOD concentration. Most of the Macroinvertebrate families had low level of tolerance to TP concentration; besides the above-mentioned families, Gyrinidae, Chironomidae, Muscidae, Simuliidae, Baetidae, Caenidae, Ephemerellidae, Heptageniidae, Gerridae, Neucoridae, Aeshinidae, Lestidae, Hydropsychidae, Lepidostomatidae and Leptoceridae were tolerant to TP at a level below 0.1 mg/l. The optimum concentration that all the orders could withstand were however different for all the three water quality parameters.

Table 14: Optimum and tolerance levels of macroinvertebrate families to TON, TP and BOD in River Sosiani during the study period

	TON		TP		BOD	
Family	**Optimum**	**Tolerance**	**Optimum**	**Tolerance**	**Optimum**	**Tolerance**
Corixidae	1.097	**0.010**	0.338	**0.010**	4.960	**0.010**
Gyrinidae	0.828	0.313	0.110	**0.071**	2.308	0.772
Scirtidae	0.888	0.148	0.194	0.102	3.222	1.229
Potamonautidae	0.706	0.326	0.157	0.134	2.913	1.505
Chironomidae	0.898	0.348	0.177	**0.088**	2.972	0.922
Muscidae	1.149	**0.037**	0.285	**0.037**	4.142	0.578
Simuliidae	0.963	0.199	0.182	**0.077**	3.027	0.886
Baetidae	1.140	0.152	0.230	**0.082**	3.642	0.957
Baetisidae	0.940	**0.010**	0.152	**0.010**	2.410	**0.010**
Caenidae	1.031	**0.071**	0.123	**0.095**	2.401	1.046
Emphemerellidae	0.235	**2.78 E-17**	0.040	**0.010**	1.753	**0.010**
Ephemeralidae	0.646	0.108	0.054	**0.005**	1.709	**0.043**
Heptageniidae	1.045	0.243	0.214	**0.084**	3.288	0.833
Siphlonuridae	1.097	**0.010**	0.338	**0.010**	4.960	**0.010**
Gerridae	0.615	0.327	0.072	**0.034**	1.944	0.267
Neucoridae	0.916	**0.084**	0.138	**0.051**	2.404	0.574
Gerridae	0.862	**0.010**	0.044	**0.010**	1.623	**0.010**
Crambidae	0.909	0.154	0.208	0.106	3.396	1.277
Aeshinidae	0.747	0.205	0.117	**0.054**	2.343	0.581
Gomphidae	0.235	**0.000**	0.040	**0.010**	1.753	**0.010**
Lestidae	0.998	**0.040**	0.110	**0.087**	2.259	1.004
Libellulidae	0.992	**0.010**	0.069	**0.010**	1.820	**0.010**
Caddisfly	0.235	**0.010**	0.040	**0.010**	1.753	**0.010**
Ecnomidae	0.862	**0.010**	0.044	**0.010**	1.623	**0.010**
Hydropsychidae	1.016	0.173	0.177	**0.074**	2.927	0.880
Lepidostomatidae	1.140	0.139	0.247	**0.048**	3.613	0.476
Leptoceridae	0.922	**0.098**	0.087	**0.025**	1.998	0.251
Polycentropodiae	0.992	**0.010**	0.069	**0.010**	1.820	**0.010**
Sphaeriidae	0.727	0.393	0.174	0.128	3.127	1.408

4.5. Developing an Index for Monitoring the Health of River Sosiani

4.5.1. Pollution Metric for River Sosiani

Pollution Metrict for River Sosiani was computed from the vector dispalement of PC 1 with the three water quality indicators of pollution (BOD, TON and TP) among the stations and so, the vector displacements were used to compute the Pollution Matrics for River Sosiani (Table 15). Station 5 before Huruma sewage treatment ponds had the largest vector displacement in both wet and dry season (0.55159847 and 0.55145498 respectively) while St 1 had the least vector displacement in both seasons (0.26826 in wet and 0.3438 in dry season). The highest PMRS at St 5 Bf scored 1 indicating the station to be the most polluted area, while the lowest PMRS (score ≈ 0) being the least polluted area. Station 5 Bf had the highest PMRS (1) in both wet and dry season and the reference site had the least PMRS in both seasons (0.26826 in wet and 0.3438 in dry seasons).

Table 15: PC eigen-vectors used to develop metrics with the TON, TP and BOD.

Wet Season	**99.3%**	**0.70%**		**Dry season**	**99.2%**	**0.8%**	
	PC 1	PC 2			PC 1	PC 2	
BOD	**0.955**	0.294		**BOD**	**0.955**	-0.288	
TON	**0.293**	-0.956		**TON**	**0.292**	0.955	
TP	**0.045**	-0.019		**TP**	**0.057**	-0.076	
	PC 1	PC 2	**Score (PMRS)**		PC 1	PC 2	**Score (PMRS)**
St 1	**0.148**	0.216	**0.268**	**St 1**	**0.190**	-0.369	**0.344**
St 2 Bf	**0.186**	0.139	**0.337**	**St 2 Bf**	**0.199**	0.081	**0.360**
St 2 Aft	**0.183**	-0.414	**0.331**	**St 2 Aft**	**0.270**	0.079	**0.489**
St 3 Bf	**0.175**	-0.545	**0.318**	**St 3 Bf**	**0.196**	0.457	**0.356**
St 3 Aft	**0.257**	-0.360	**0.466**	**St 3 Aft**	**0.281**	0.250	**0.509**
St 4	**0.256**	-0.253	**0.464**	**St 4**	**0.221**	0.543	**0.400**
St 5 Bf	**0.552**	0.498	**1.000**	**St 5 Bf**	**0.552**	-0.529	**1.000**
St 5 Aft	**0.501**	0.100	**0.908**	**St 5 Aft**	**0.447**	0.066	**0.811**
St 6	**0.439**	-0.124	**0.796**	**St 6**	**0.426**	0.035	**0.773**

Spearman's R pairwise comparison of relationship between the chosen pollution indicators and the PMRS for both wet and dry season is presented in Table 16. The PMRS_w (w≡ wet season) and PMRS_d (d≡dry season) had an r-value of 0.95. The r and p-value for PMRS_w with TON (r = 0.86: p < 0.001), for TP (r = 0.95: p < 0.0001) and BOD (r = 0.98: p < 0.00001) mean concentrations for the wet season, and TON (r = 0.87: p < 0.001), for TP (r = 0.93: p < 0.0001) and BOD (r = 0.88: p < 0.001) mean concentrations for the dry season. While the r and p-value for PMRS_d in the dry season with TON (r = 0.85: p < 0.001), a for TP (r = 1: p < 0.00001) and BOD (r = 0.92: p < 0.001) mean concentrations for the wet season and TON (r = 0.83:

$p < 0.001$), for TP ($r = 0.98$: $p < 0.00001$) and BOD ($r = 0.95$: $p < 0.0001$) for the dry season. All p values were < 0.05.

Table 16: Spearman's correlation of the PMRS with TON, TP and BOD during the sampling period

* = p < 0.01, ** = p < 0.001, *** = p < 0.0001 and **** p < 0.00001.
w ≡ wet season and d ≡ dry season.

Spearman's correlation; Correlation coefficients and p values								
	PMRS w	**PMRS d**	**BOD w**	**TON w**	**TP w**	**BOD d**	**TON d**	**TP d**
PMRS w		***	****	**	***	**	**	***
PMRS d	**0.95**		**	**	****	***	**	****
BOD w	**0.98**	**0.92**		**	**	**	**	**
TON w	**0.86**	**0.85**	0.84		**	*	****	**
TP w	**0.95**	**0.98**	0.92	0.85		***	**	****
BOD d	**0.88**	**0.95**	**0.85**	0.78	0.95		*	***
TON d	**0.87**	**0.83**	0.88	**0.97**	0.83	0.77		**
TP d	**0.93**	**0.98**	0.9	0.84	**0.98**	0.93	0.82	

Table 17 shows the final PMRS from the principal component vectors used to classify the stations according to the five quality classes. Scores were developed for these five quality classes; excellent (1), good (0.8), moderate (0.6), poor (0.4) and Bad (0.2).

Table 17: PC 1 used to develop water quality classification at River Sosiani during sampling period

Stations	PC Class	Final PMRS	Class	Score
	0-0.2		Excellent	1
St 1	**0.21-0.4**	0.306	Good	0.8
St 2 Bf	**0.21-0.4**	0.349	Good	0.8
St 2 Aft	**0.41-0.6**	0.410	Moderate	0.6
St 3 Bf	**0.21-0.4**	0.337	Good	0.8
St 3 Aft	**0.41-0.6**	0.488	Moderate	0.6
St 4	**0.41-0.6**	0.432	Moderate	0.6
St 5 Bf	**0.81-1**	1.000	Bad	0.2
St 5 Aft	**0.81-1**	0.860	Bad	0.2
St 6	**0.61-0.8**	0.784	Poor	0.4

4.5.2. Habitat Index for River Sosiani

Habitat Index for River Sosiani (HIRS) was developed from the Habitat Index (HI), Dominance index and Species richness index (Table 18). The scores for these three indices were categorized in each station, according to the water quality class, and the equation for HIRS was used to evaluate the index value for each station hence, the quality of the station. Station 1, St 2 and St 4 were of good quality class (G), St 3 was moderate in quality while St 5 and St 6 were poor in quality.

Table 18: Physical Habitat Index for River Sosiani determined during the study period

HI ≡ Habitat index, QC ≡ Quality Class, D/Dmax≡Dominance and Maximum Dominance, S/Smax≡Richness and Maximum Richness, HIRS≡Habitat Index for River Sosiani, G≡Good quality, M≡Moderate quality and P≡Poor quality

Stations			Macroinvertebrates				Macrophytes				
	HI	QC	D/Dmax	QC	S/Smax	QC	S/Smax	QC	D/Dmax	QC	**HIRS**
St 1	0.10	1	0.60	0.6	0.28	0.8	0.25	0.8	0.80	0.2	0.68 G
St 2	0.35	0.8	0.61	0.4	0.64	0.4	0.56	0.6	0.34	0.8	0.60 G
St 3	0.35	0.8	0.90	0.2	0.32	0.8	1.00	0.2	0.24	0.8	0.56 M
St 4	0.40	0.8	0.59	0.2	0.31	0.8	0.69	0.4	0.26	0.8	0.59 M
St 5	0.85	0.2	1.00	0.2	1.00	0.2	0.69	0.4	0.28	0.8	0.36 P
St 6	0.90	0.2	0.88	0.2	0.45	0.6	0.25	0.8	1.00	0.2	0.40 P

4.5.3. Biotic Index for Rivers Sosiani

Macrophyte species found at different stations were assigned scores to identify them with the stations or pollution area where they were found (Table 19). Four macrophyte species that were only found in St 1 had a score of 0.8 (*Schoenoplectus corymbosus, Polygonum pulchrum, Polygonum strigosum and Pycreus nitidus*). Those found in St 2 and St 3 were assigned the average of before and after Elegrin Dam and before and after Two Rivers Dam score (0.7), while those found at St 4 had a score of 0.6. At St 5, they had a score of 0.2 while at St 6, their score was 0.4.

Species found at two or more stations were assigned an average of the corresponding scores.

Table 19: Scores for different macrophyte species along River Sosiani during the sampling period.

Species	Score	Species	Score
Aeschenomene abyssinica	**0.7**	*Ludwigia leptocarpa*	**0.45**
Aponogeton stulmanii	**0.6**	*Maranta arundinacea*	**0.7**
Crassula gravinkii	**0.55**	*Marchantia polymorpha*	**0.7**
Cyperus alternifolius	**0.7**	*Murdannia simplex*	**0.7**
Cyperus laevigatus	**0.7**	*Nymphaea lotus*	**0.4**
Cyperus rigidifolius	**0.733**	*Panicum hymeniochilum*	**0.65**
Cyperus strigosum	**0.7**	*Peucedanum aculeolatum*	**0.7**
Echinochloa pyramidalis	**0.45**	*Polygonum pulchrum*	**0.8**
Eleocharis radicans	**0.45**	*Polygonum salicifolia*	**0.65**
Elodea Canadensis	**0.4**	*Polygonum setosulum*	**0.7**
Epilobium hirsutum	**0.53**	*Polygonum strigosum*	**0.8**
Eragrostis chalarothyrsus	**0.45**	*Potamogeton schweinfurthii*	**0.4**
Fimbristylis complanata	**0.7**	*Pycreus nitidus*	**0.8**
Floscopa glomerata	**0.4**	*Ranunculus multifidus*	**0.7**
Fuirena stricta	**0.7**	*Rotala tenella*	**0.65**
Hoehneria vernonioides	**0.5**	*Schoenoplectus corymbosus*	**0.8**
Hydrocotyle sibthorpioides	**0.7**	*Sphaeranthus suaveolens*	**0.6**
Hygrophylla auriculata	**0.45**	*Spyrogyra*	**0.6**
Leersia hexandra	**0.3**	*Typha domingensis*	**0.65**
Lemna gibba	**0.2**	*Typha latifolia*	**0.7**
Ludwigia abyssinica	**0.2**		

Macroinvertebrate families were also assigned scores corresponding to the stations they were found in as shown in Table 20. The five families found only at station 1 were assigned a score of 0.8 (Caddisfly, Ephemeralidae, Ephemeralidae, Gerridae and Gomphidae). Most of the families were however found in more than one station and therefore were assigned an average score from the summation of all the scores corresponding to these stations.

Table 20: Scores assigned to different macroinvertebrate families along River Sosiani during the study period.

Family	Score	Family	Score
Aeshinidae	**0.55**	Heptageniidae	**0.6**
Baetidae	**0.48**	Hydropsychidae	**0.48**
Baetisidae	**0.6**	Lepidostomatidae	**0.6**
Caddisfly	**0.8**	Leptoceridae	**0.6**
Caenidae	**0.4**	Lestidae	**0.46**
Chironomidae	**0.46**	Libellulidae	**0.6**
Corixidae	**0.20**	Muscidae	**0.3**
Crambidae	**0.4**	Neucoridae	**0.5**
Ecnomidae	**0.8**	Polycentropodiae	**0.6**
Emphemerellidae	**0.8**	Potamonautidae	**0.6**
Ephemeralidae	**0.8**	Scirtidae	**0.4**
Gerridae	**0.7**	Simuliidae	**0.43**
Gerridae	**0.8**	Siphlonuridae	**0.2**
Gomphidae	**0.8**	Sphaeriidae	**0.45**
Gyrinidae	**0.54**		

4.5.4. Evaluation of the Stations along the River

Macrophyte and macroinvertebrates scores were then used to develop Biotic Index for River Sosiani Health (BIRSH) to asses rive health along the sampling stations as shown in Figure 22. Macrophyte index evaluated St 1 in the range of excellent to good quality while macroinvertebrate index evaluated the same station in the range of good to moderate quality. Station 2 was within the range of good quality with macrophytes while the macroinvertebrates evaluated it to be moderate. Station 3 and St 4 had some interaction in the range of the two indices though also being of moderate to good in quality. At St 5, macroinvertebrate index scored was slightly higher than macrophyte index. The two BIRSH scores were however not significantly different from each other due to their interaction within their range of evaluation (error bars). Station 5 was classified to range between moderate to poor in quality and, the same observation was made in the last station sampled along the river (St 6), but though with slight improvement in water quality compared to St 5.

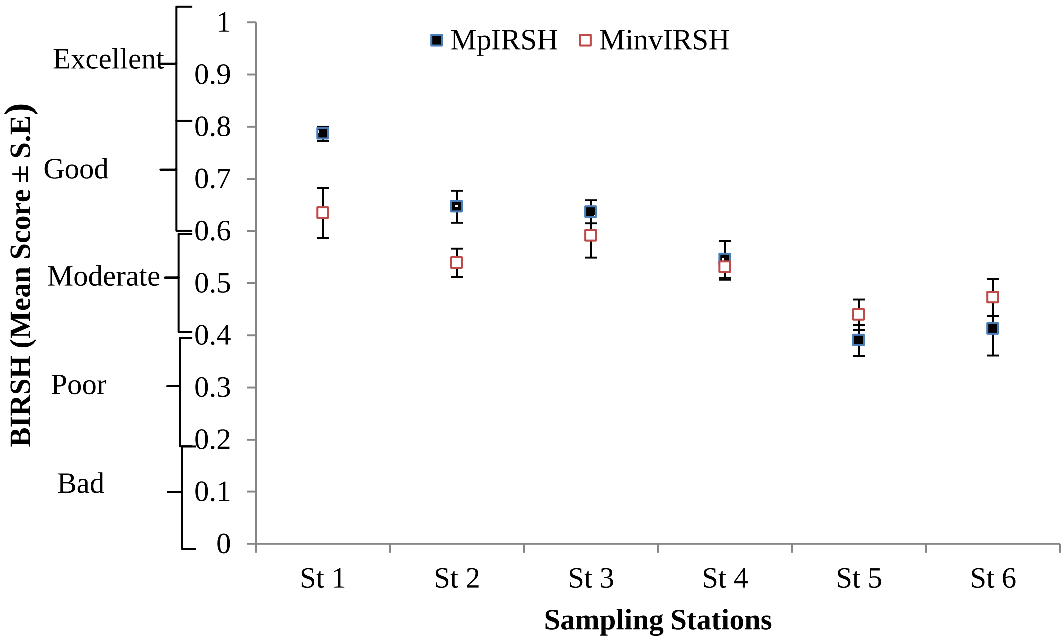

Figure 17: The mean BIRSH (± S.E) for different quality class and stations along River Sosiani during the study period

4.6. Integrated Index for River Sosiani

Integrated index to evaluate the health of River Sosiani was then calculated (Figure 24) with the range of pollution level at each station (± S.E). Only St 1 was in the range of good quality class, St 2 to St 4 were in the range of moderate quality class while St 5 was in the range of poor quality class. Station 6 showed a bit of improvement compared to St 5 but was not significantly different from it. Station 2, St 3 and St 4 were also not significantly different from each other but were significantly different from St 5 and St 6. Station 1 was significantly different from all the other stations as shown with the standard error.

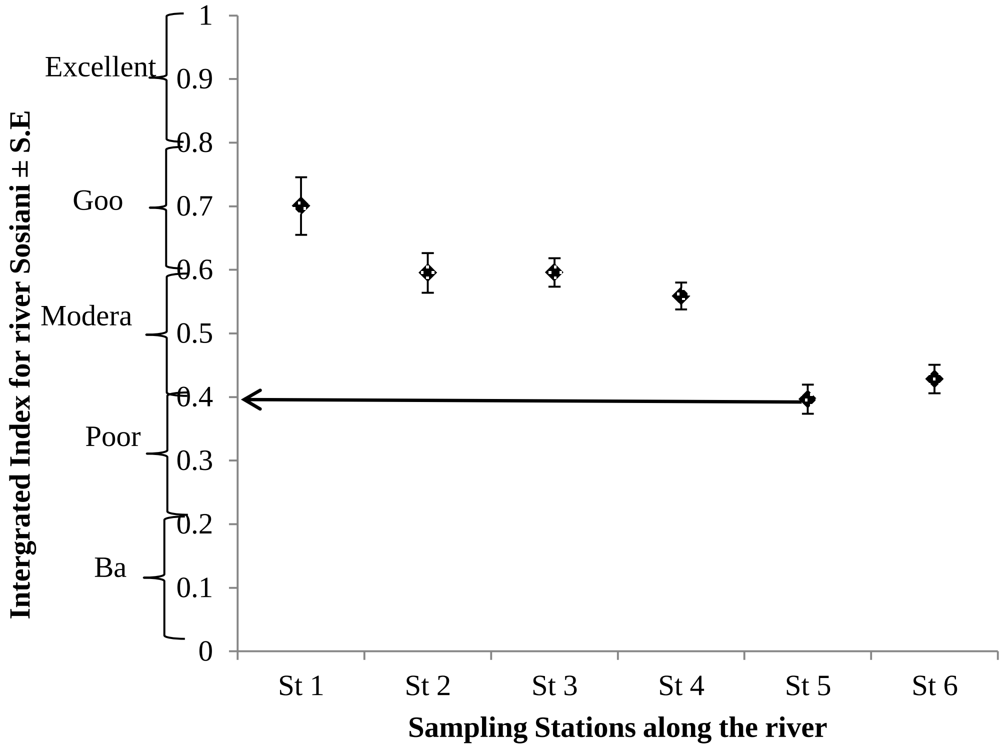

Figure 18: Variation of Integrated Index for River Sosiani (± S. E) determined along the river during the study period

CHAPTER FIVE

DISCUSSION

5.1.Physical Characteristics of River Sosiani

This study observed that the physical characteristics of River Sosiani was substantially changing from the upper catchment, downstream. Its width generally broadened to over 10 meters after St 3 as it passed through St 4 to St 6. As the river broadened, it also became deeper, had steep banks, and channeled large volume of water. The upper catchment had very clear water, but change in color was evident as from St 2 onwards. As most studies have observed about rivers, this was not exceptional, in that, its environment differed at constituent sites and, this was observed even at very short distance such as, the stations sampled before and after pollution effect like St 2, St 3and St 5. This change could not be entirely attributed to pollution, but the complexity of a river channel. Rivers are well known to exhibit fractal structural properties (De Bartolo *et al.*, 2006; Saa *et al.*, 2007) and are examples of the long-term working out of power law distributions of things like meanders (Fonstad and Marcus, 2003; Frascati and Lanzoni, 2010).

Anthropogenic activities evidently observed from St 1 to St 6 were numerous. Studies show that anthropogenic activities result in the degradation of surface water quality of aquatic systems, especially in river catchments and channel (Mahvi *et al*., 2005; Dudgeon *et al.,* 2006; May *et al*., 2006; Xiao-long *et al.,* 2007; Najafpour *et al.,* 2008; Nouri *et al.,* 2008, Karbassi *et al.,* 2008; Allan *et al.,* 2012). A range of human disturbances such as damming of the river, discharge of wastes and non-point pollution from agricultural practices directly affect River Sosiani ecosystem, an observation similar to the inference drawn from other related studies (Benini *et al*., 2010; Theodoropoulos and Iliopoulou-Georgudaki, 2010). For instance, at St 2, large-scale cattle ranch, clearing vegetation and settlement, animal grazing and fencing activities were in practice. Furthermore, two damming effect at St 2 and St 3 had considerable effect on water flow as well as the biological communities. It was observed that, though the river had widened from St 1 to St 2 before Elegrin Dam, the width lessened after the Cheboen Dam and before the Elegrin Dam (Table 2). At Elegrin Dam, there was large-scale flower farming besides other activities like fencing and log-treatment.

As the river passed through Eldoret town, a comparative site at Juakali area was selected to observe the town’s effect. Most of the solid waste disposal into the river were evident from Eldoret town onwards; burned wastes, metallic wastes from Juakali activities to polyethene and plastic deposits into the river.

The peak of anthropogenic pollution effect was observed at Huruma. At this station, suspended solid wastes from Eldoret town were still evident and, municipal discharge and the dumpsite wastes blown by wind into the river had changed the river color and odor. Human settlement and farming activities were also along the riparian zone. At some time during the rainy seasons, the sewage ponds had flooded and were overflowing into the river. Physical habitat of the river was therefore under serious degradation from destructive human activities that threatened this ecosystem’s health.

5.2. Physico-chemical Water Quality

The study observed that most of the mean measurements in physico-chemical water quality parameters had a general trend of increasing concentration such as TDS, TP, TON, Conductivity and BOD. Dissolved oxygen and pH concentration fluctuated but generally declined, indicating that water quality was becoming more acidic and poor to sustain diverse biological communities that are sensitive to low oxygen concentration. This worsened during dry season since; the concentrations were higher and significantly different from wet season concentration. As observed in many studies, seasonal variation in precipitation and surface run-off have a strong effect on the river discharge and subsequently on the concentration of pollutants in river water (Monavari and Guieysse, 2007; Khadka and Khanal, 2008; Mtethiwa *et al.,* 2008; Najafbour *et al.,* 2008) which was not exempt in Sosiani River. The volume of River Sosiani had subsided in dry season, resulting to increase in concentration of physico-chemical water quality parameters.

Seasonal variation for most of the measured water quality parameter had *r*-values > 0.8 and p values ≤ 0.005 (Table 6) indicating that pollution correlated with the sampling sites but significantly differed comparing the two seasons. This however did not substitute the fact that pollution was still evident even during wet season. The inference from the results of this study were much related to the research findings/recorded that most of surface water pollution is attributed to human activities (Milovanovic, 2007) such as wastewater, effluents and other surface water degradation practices (Mahvi *et al.*, 2005; Liao *et al.,* 2007; Nouri *et al.,* 2008; Zhou *et al*., 2007; Reza and Singh, 2010; Tanriverdi *et al*., 2010) like agricultural land use that strongly influence nutrient and sediment (Sliva and Williams, 2001; Turner and

Rabalais, 2003; Ahearn *et al*., 2005), The same activities were evident along River Sosiani. The pollution effect was therefore not only an attribute of seasonality but was specific to these sites, corresponding to the anthropogenic activities at the stations, practiced in both wet and dry season and therefore, degrading the water quality.

5.2.1. Spatial Changes in Physico-chemical Water Quality

Spatial variation in physico-chemical water quality parameters among stations in River Sosiani was explored with multivariate analysis. This helps in interpretation of complex data matrices to better understand the water quality and ecological status of the studied ecosystem, a fact also observed by (Vega *et al.,* 1998; Wunderlin *et al.*, 2001; Reghunath *et al.,* 2002). This further allowed for identification of possible factors sources that influenced water quality at different stations and, offered solution for identifying environmental quality indicators along the river, just as multivariate results are interpreted in other studies (Perkins and Underwood, 2000; Voutsa *et al.,* 2001; Bengraine and Marhaba, 2003; Ouyang, 2005; Ouyang *et al.,* 2006), to develop the index used in assessing river health.

Stations in River Sosiani that were clustered had considerable similarity in the measured variables from the distant related stations to the closely related stations. Most of upper catchment/higher altitude stations (St 1, 2 and 3) were identified with nutrient pollution of agricultural activities and therefore, were grouped into one cluster for both seasons. The lower altitude stations were also grouped into another cluster (St 5 and 6) and they were more polluted with municipal watses and non-degradable solid wastes like polythenes and plastics. Lower altitude stations were therefore distantly similar to the other stations when compared at the measured physico-chemical water quality parameters along the river. Besides nutrients, BOD, TDS and conductivity concentrations were also high in them, with low DO concentrations, a possible indication of organic decomposition (Statzner *et al*, 2001).

Principal component analysis evaluated DO concentration to be high at the higher altitude stations in both seasons indicating that there was less organic pollution in them. Total dissolved solids and conductivity were high during the dry season possibly due to the subsidence in the volume of the river. However, the most meaningful inference from these results was that, water chemistry was constantly affected by nutrients from agricultural activities besides other pollution sources in both seasons. An interpretation focusing on observations from multivariate techniques used in assessment of surface waters (Helena *et al*., 2000; Sarbu and Pop, 2005; Shrestha and Kazama, 2007).

Furthermore, the results from factor analysis evaluated three main factors that influenced the change in water chemistry along River Sosiani, just as interpreted by other studies about factor alaysis (Shrestha and Kazama, 2007; Boyacioglu and Boyaciouglu, 2008; Iscen *et al.,* 2008). The first factor being, water quality parameters that generally fluctuated along the river and were also affected by seasonality like pH, Conductivity, TDS, temperature and DO. Since, the two seasons vary in temperature which also affects DO concentration and solubility of solids, futher impacting on conductivity. Biological oxygen demand and TP were the second factor, an indication of both nutrients and municipal discharge of organic pollution from the large-scale ranching (St 2 after Elegrin Dam), agricultural activities (St 3) and organic municipal wastes (St 5). The flower farms at the upper catchment and large-scale cattle ranch represented the nutrient loading while Eldoret town and Huruma sewage treatment ponds represented the loading of organic wastes; they were key pollutants in the river. Finally, the third factor that was also of concern was TON in both seasons, pointing to the nutrient loading from the agricultural area, St 2 and St 3.

The physico-chemical water quality fluctuated along River Sosiani, both seasonally and spatially. However, nutrient loading and pollution from organic wastes constantly affecting the river's health in both seasons, and was independent of the changing weather conditions. The anthropogenic activities which were practiced at these stations in both seasons were the major cause of the changing water quality. The measured physico-chemical water quality parameters were specifically indicators of agriculture and organic wastes, and were limited to the identification of these pollution effects in water chemistry along River Sosiani. Evaluation of the status of the physical habitat showed some congruence between the observed degradation of the riparian zone and changes in water quality. It was imperative to employ biological communities that reside in the same habitat; their response incorporates both physical habitat degradation and change in the river physico-chemistry as observe in many studies (Iliopoulou-Georgudaki *et al.,* 2003; Franzle, 2006; Beyene *et al.,* 2009; Birk *et al.,* 2012). This gave evidence to the incorporation of macrophytes and macroinveretebrates as indicators in the study

5.3. Vegetation along River Sosiani

The findings of this study also showed that River Sosiani was still vegetation rich. At the sampling stations, 263 plant species in 75 families were observed; most of which were indigenous vegetation. Only 17 species (≈ 6%) were exotic. However, most of the exotic species were found at St 4 where tree nursery was practiced, and some could be observed permanently grown at the station. Besides practicing tree nursery, other human influence at this station was inevitable since, the bridge is near Eldoret town and along Eldoret-Nairobi highway. At the bridge therefore, other practices like car wash suffice run-off from the road and bathing were prominent. Station 1 and St 3 too had some exotic vegetation; but none was sampled at St 2. Since exotic vegetation are introduced into these areas, and are among the major threats to aquatic ecosystems (Dudgeon *et al.,* 2006; Geist and Auerswald, 2007), they were indication of habitat change through intrusion by human influence at these sites along River Sosiani.

The riparian zone vegetation had 18 different plant habits along the river. More than 11 habits (≈ 61 %) were present in each of the first three stations showing that the ecosystem change through vegetation alteration was less practiced in them. Instead, these stations being in a high altitude area, the anthropogenic activities practiced around them were more of agricultural practices which contributed to nutrient loading of TON and TP and thus supporting vegetation growth, a similar observation made by documented studies (Arimoro and Ikomi, 2009; Doren *et al.,* 2009). The habits however fluctuated in their abundance at the downstream stations. The riparian zone at St 4 had introduced vegetation that affected the natural complexity of vegetation growth. At St 5, there were other activities like vegetable planting and settlement along the riverbanks. Furthermore, the sewage treatment ponds were constructed along the river channel, which hanged the vegetation structure of the banks considerably. Studies have shown that, vegetated riparian zones adjacent to rivers and streams, can greatly mitigate nutrients, sediment from surface through deposition, absorption and denitrification, yet, human activities, and primarily land use practices, have dramatically reduced this capacity (Li *et al*. 2009). The efficiency of self-purification mechanism of River Sosiani is therefore compromised. Increased pollution and change in vegetation structure through clearing, and introduction of invasive species are threats to the river ecosystem health and function.

The aquatic, semi-aquatic and riverine vegetation at the riparian zone and ecotone of the river also changed from the natural riverine ecosystem. The first three stations had all the three groups of vegetation; though St 2 and St 3 had more aquatic vegetation than St 1. This may have been as a result of two large dams constructed at St 2 and St 3 creating a lacustrine wetland environment thus changing the vegetation growth substantially. As a result, the riverine vegetation were more abundant at St 1 than the other two consercutive upper catchment stations. Except for St 5, which also had sewage ponds and most of the aquatic and semi-aquatic vegetation, St 4 and St 6 had fewer of this vegetation since, they had no damming effect, as observed through studies that, damming effect has an influence on vegetation and especially macrophytes (Riis *et al.,* 2008; Catford *et al.,* 2011) which concurs with observation in Sosiani. Documentation also has it that, vegetation in wetland ecosystems are sensitive to changes in environmental conditions (Hrivnack, 2005) which dictate their temporal and spatial distribution (Acreman and Ferguson, 2010). A similar observation made in River Sosiani. Aquatic vegetation was observed plentiful (21 species) at St 3 where, pollution effect due to nutrient loads from agricultural activities at the previous station, in-addition to the damming effect that seemed to limit/restrict the natural flow of River Sosiani, significantly affecting the water quality and the growth of macrophytes.

The abundance of both aquatic and semi-aquatic vegetation increased with increasing concentration of the nutrients, while riverine vegetation increased with increasing TON. Total phosphorous concentration however seemed to limit their growth. This concurred with other studies which have deduced that, different macrophyte species may have a different tolerance to increased nutrient availability (Sand-Jensen *et al*., 2008; Bakker *et al.,* 2010). Station 5 and St 6 with other pollution loading besides the nutrients; suspended solid wastes of both degradable and non-degradable wastes, suspended sediments had fewer plants as these pollutants could have attributed to limiting vegetation growth. Kors *et al.,* 2012 also observed the same. The effect of TON and TP concentration was however not clearly observed in St 5 and St 6 due to the multiple pollution effect which deteriorated water quality to the extent of limiting most of biological communities. A similar deduction was drawn by Meng *et al*., 2009.

5.3.1. Influence of TON and TP on Macrophyte Abundance.

Emergent macrophytes were abundant at St 3 showed an increasing trend with the nutrients while rooted floating and submerged macrophytes species were very few in the sampled vegetation. The emergent species were however sensitive to TON loading than TP along the river thus a bit contrary to what other studies have inferred about the response of macrophytes (Harper, 1992; Paerl, 1997; Wetzel, 2001; Dodds *et al*., 2002; Smith, 2003) though of submersed group. Concentration of TP was also very low in the mean measurement compared to TON. Moreover, most of the macrophytes along the river were emergent vegetation accounting for 85 % of the macrophytes sampled possibly due to the gradient and velocity at the high altitude stations and the increasing depth of the river at the lower altitude stations, which could not well support submersed vegetation (Sand-Jensen, 1989; Riis and Biggs, 2003; Lacoul and Freedman 2006).

At St 3, the emergent species that showed a positive response to increasing concentration of TON were *Cyperus alternifolius, Cyperus laevigatus, Cyperus rigidifolius, Cyperus strigosum, Echinochloa pyramidalis, Eleocharis radicans, Hygrophylla auriculata, Hydrocotyle sibthorpioides, Ludwigia leptocarpa, Maranta arundinacea, Marchantia polymorpha, Murdannia simplex, Panicum hymeniochilum, Peucedanum aculeolatum, Polygonum salicifolia, Polygonum setosulum, Ranunculus multifidus, Rotala tenella, Typha domingensis, Typha latifolia.* The observation at River Sosiani concurred with many studies that have evaluated macrophytes as reliable indicators for nutrient loading in streams (Dodkins *et al*., 2005; Johnson *et al*., 2006 a, b; Hrivnack *et al.*, 2007; Demars and Thiebaut, 2008; Demars and Tremolieres, 2009; Lukas *et al.*, 2009; Kopec *et al.*, 2010; Birk and Wilby, 2010; Demars *et al*., 2012).

5.4. Macroinvertebrate Communities

Macroinvertebrate communities responded to the changing river environment and water chemistry along River Sosiani. At the first station, where pollution and disturbance were minimum, there were 8 out of 9 orders identified and, at least 1 family was present with no order dominating the other. This however, dropped at St 2 before the Elegrin Dam, where several disturbance activities like cattle drinking, settlements and fetching water, which frequently disturbed the fast flowing shallow river creating turbulence and therefore, the benthic environment.

The number of orders identified increased to 8 at a sampling site that was less than 3 km after Elegrin Dam. The site was influenced by nutrient loading from the waste discharge from the ranch (Figure 6a). Most studies have observed that, nutrient loading enhances primary productivity and macrophyte growth which further influences velocities (Watson, 1987; Gurnell and Midgley, 1994; Riis and Biggs, 2003; Green, 2005), sediment patterns (Sand-Jensen and Madsen, 1992; Riis, 2000), water quality (Sculthorpe, 1967; Riis and Biggs, 2003) and providing structural habitat diversity (Hearne and Armitage, 1993; Baattrup-Pedersen *et al*., 2003) in a river channel. The macroinvertebrate taxa therefore changed along the pollution gradient. For instance, some orders dominated the consecutive stations such as, after the Elegrin Dam in St 2, like Decapoda, and in St 3 before and after the Two River's Dam was dominated by Trichoptera. The latter orders have generally been considered in other studies as good indicators of pollution (Walker, 2001; Porinchu and MacDonald, 2003; Álvarez-Cabria et al., 2010; Greffard *et al.*, 2011).

Two orders dominated St 5 and St 6; Epehemeroptera and Diptera of which have been considered widely as indicators of pollution and developing an index. Baetis family in the order Epemeroptera (Atobatele *et al*., 2005; Arimoro *et al*., 2007) with chironomid family, in the order Diptera can tolerate high level of pollution (Rosenberg, 1992; Walker, 2001; Iliopoulos-Georgudaski *et al* 2003; Bonada *et al*., 2005; Greffard *et al.*, 2011; Bio *et al.*, 2011; Keci *et al.*, 2012). They were abundant at St 5 near sewage discharge area, with mixed pollution effect of municipal, agricultural and urban wastes from Eldoret town. St 5 was therefore considered the most polluted site compared to the other sampling stations along the river.

Most of the families identified had a low tolerance level to TP < 0.1 mg/l (25 out of the 29 families identified), the exceptional families were Scirtidae, Potamonautidae, Crambidae and Sphaeriidae, 14 out of 29 families had the same tolerance level to TON and 11 out of 29 families had the same tolerance level to BOD. This suggested that the sampled macroinvertebrate families were very sensitive to changing TP concentrations more than TON and BOD. The diversity indices (Simpson diversity, Dominance and Evenness) evaluated Huruma Sewage pond area to have the lowest Evenness, highest Dominance and low Simpson diversity; indicating that only those species in the families that could tolerate high pollution effect were abundant at this site, a similar finding made by Gallardo *et al.,* (2008).

Rivers are very complex ecosystems; using single factor such as physico-chemical index alone is not able to completely reflect a river regime (Meng *et al.,* 2009). The study of the physical habitat, physico-chemical water quality and biological communities was therefore important for River Sosiani. Neither the biological index nor the physical habitat index on its own, can fully evaluate a river health. The integrated assessment of River Sosiani with physical habitat, physico-chemical water quality parameters and biological indicators of pollution gave a holistic assessment criteria.

5.5. Developing River Sosiani Health Index

Pollution metrics developed for River Sosiani resulted from the measured water quality parameters that significantly affected it. This was deduced from principal component analysis and factor analysis, which had a strong factor loading of TON, TP and BOD concentrations in both wet and dry seasons. These were therefore the major parameters, from the measured variables, that defined pollution along the river channel, and at the sampling stations. Since the vector displacement of a parameter in principal component corresponds to the level of influence that that parameter has along the axis of the component, the three water quality parameters used to evaluate the extent of their effect on the stations. The study focused on using the vector displacements from the stations and developed an unbiased scoring criteria to categorize these stations in the quality classes generated, rather than to explain the variance (Skoulikidis *et al.,* 2003; 2004; and also Meng *et al.,* 2009).

From the results, St 5 (Huruma site) was the most degraded area with TON, TP and BOD as the indicators of pollution. All other stations' scores were computed relative to this station and categorized in the water quality classes as Excellent, Good, Moderate, Poor and Bad. The categorization was modified from the European Water Framework Directives' (EU-WFD) classification system in which, with the advent of large-scale monitoring, individual stream reaches are categorized on a continuum of poor to excellent condition, and whole regions can be compared with regard to average level of impairment (Paulsen *et al*., 2008; Davies *et al*., 2010; Allan *et al.,* 2012).

5.5.1. Pollution Metric for River Sosiani

Pollution metrics for assessing River Sosiani was developed from the principal component scores of the stations due to the fact that, environmental data is characterized by high variability; because of the variety of natural and anthropogenic influences (Reisenhofer *et al*., 1996; Spanos *et al*., 2003) and multivariate statistical methods apply widely to interpret and derive useful information from multiple spatial and temporal parameter measurement data about water quality studies (Helena *et al*., 2000; Bengraine and Marhaba, 2003; Liu *et al*., 2003; Sundaray, 2010).

Pollution Metric for River Sosiani categorized St 1 to be in good qality class. The human intrusion at the catchment and animal wastes had some influence on the water quality. Station 2 and St 3 were intermediate between good and moderate quality class, they too had human disturbance activities such as damming of the river, agricultural activities and cattle-ranch and a large scale flower farm practice. They were the major source of nutrient loading into the river. However, due to the continuous flow and self-cleansing capacity of the river, pollution was diluted by the water downstream. Station 4 which had daily human disturbance practices like car wash suface runoff and tree nursery; all of which stirred the water on a frequent basis was categorized in the moderate quality class. Station 5 near the sewage pond area had the most polluted water that received all the municipal discharge from Eldoret town and the nutrient loads; agricultural activities from the previous station. Furthermore, the sewage treatment ponds were just adjacent to the river, in-addition to being one of the low altitude areas compared to the other stations. It was classified to be of bad quality class. Lastly, St 6 was of poor quality class; showing a bit of improvement compared to the Huruma station. No station was categorized in the excellent quality class since, they all had anthropogenic activity of degradation effect to the health of River Sosiani, whether of physical habitat, water quality or biological communities.

5.5.2. Habitat Index for River Sosiani

Habitat Index was different from the two biological indices in that, it evaluated the observed anthropogenic activities of human disturbance at the riparian zone that were practiced along the river channel. Unlike the measured parameters which had to be evaluated for interrelationships, it incorporated activities evidently degrading the river ecosystem and the riparian zone. Apart from human disturbance, agricultural and municipal effect, macrophyte and macroinvertebrate dominance and richness too were incorporated in the calculation. This was drawn from the principle known from studies that, species/taxa of organisms that are tolerant to pollution, dominate degraded waters (Raunio *et al.*, 2007); multiple stress for macroinvertebrates (Nijboer *et al* 2005; Hering *et al.*, 2006) especially of municipal source and nutrients (Schneider *et al.*, 2000; Paavola *et al.*, 2003) for macrophytes. The richness therefore giving the number of individuals present in a site and dominance index accounted for the few individuals comprising the bulk of the count; if it had a combination of the different taxa observed along the river or only a few taxa.

Regression analysis of PMRS was stronger for TON and BOD that TP for River Sosiani metrics, possibly due to the two parameters being of high concentration measurement in the river than TP. This is consistent with studies that have compared strength and sensitivity tests for metrics using linear regression analysis (Lyche-Solheim *et al.*, 2013). The nutrients were considered reliable indicators of agricultural and municipal pollution along the river since, increase or decrease in their concentration could be quantified by the pollution metric score/value. Regression analysis of PMRS with dominance and richness of macroinvertebrates increased with the increase in PMRS value as also observed with Sandin and Hering, (2004) This relationship that confirmed that pollution tolerant species at the degraded sites are those of orders like finding, those of Orders like Ephemeroptera (Crew *et al.,* 2007) and Diptera (Sanchez-Montayo *et al.,* 2010) which dominated polluted sites of municipal waste (Yung-Chul *et al.,* 2012).

Unlike macroinvertebrates, the relationship of macrophyte dominance and richness to TON and TP was better presented, though both had an increase in richness and a decrease in dominance with increasing nutrient loads. This could possibly be due to the fact that TON concentration was higher than TP at the sampling sites along the river. They however became more diverse with increasing nutrient loading. This was consistent with most studies which have deduced the response of macrophytes to increase with nutrients, especially of nitrogenous and phosphorous source (Dodkins *et al*., 2005; Johnson *et al*., 2006a,b Demars and Thie´baut, 2008; Demars and Tre´molie`res, 2009; Dermas *et al.*, 2012), and therefore, indices of nutrient loading.

Pollution Metric for River Sosiani was finally regressed with the three indices; Habitat index for River Sosiani, Macrophyte and Macroinvertebrate index for River Sosiani Health (BIRSH). The linear relationship of these three indices with pollution metrics inferred their reliability in assessment. Macroinvertebrate graph was gently sloping and therefore had a wide range of sensitivity (horizontal axis) over a small change in PMRS (vertical axis) compared to Habitat and Macrophyte indices (Figure 23). Thie is consistent with other studies which support the notion that macroinvertebrates can measure a range of stress gradients of different pollution source (Nijboer *et al.,* 2005; Hering *et al.,* 2006; Raunio *et al.,* 2007; Meng *et al.,* 2009).

5.5.3. Biotic Index for River Sosiani Health

Macrophytes responded to the changing water quality, and especially those of nutrient pollution effect, in that, their abundance at a station was influenced by the concentration of the nutrients. Multiple pollution effect of combined nutrient, municipal and suspended non-degradable solids that affected water quality, color and transparency also seemed to limit their growth. The findings were important in the deduction to use them as indicators of pollution at the sampling stations along the river. Macroinvertebrates also responded to the changing water quality. Their diversity and dominance at some sampling stations, corresponded to municipal wastes of organic pollution, and benthic nature which was affected by human disturbance activities frequently stirring the shallow river bed at the upper altitude stations and therefore, their ecosystem. They were incorporated in the assessment of River Sosiani health since, their response to human activities could be analyzed.

Since numerous studies support biological communities to integrate the effects of different stressors (Barbour *et al.,* 2000), the advent of bio-assessment provided a more comprehensive and effective monitoring and assessment strategy. Macrophyte and macroinvertebrate biotic indices responded differently to pollution gradient. Stations like Elegrin and Two Rivers Dam identified with nutrient loading, the macroinvertebrate Index measured lower than macrophyte index (Figure 22). Furthermore the range of evaluation for St 1 and 2 in the quality class were significantly different comparing the two biotic indices; macroinvertebrate index scored lower than macrophyte index. This showed that macroinvertebrates were not good indicators on nutrient pollution. Other studies confirm that, macroinvertebrate are sensitive to different pollution effect than macrophyte, organic pollution (Statzner *et al*, 2001), hydromorphological degradation (Buffagni *et al*., 2004; Lorenz *et al*., 2004) and general stress (Doledec *et al.*,, 1999; Karr and Chu,1999; Nijboer *et al.*, 2005) unlike macrophytes which are mainly focused on assessing nutrient stress (Hering *et al.*, 2006). This was also observed at St 6 where, the river had started to recover from the heavy pollution effect. Macroinvertebrate index was quick in response to show the recovery state than macrophyte index (Figure 22). It was necessary to develop both of the indices in evaluation since biological assessment data can be extracted for further insights, as when the traits or tolerances of particular species can be strongly associated with particular stressors (Yuan, 2004; Pollard and Yuan, 2010). Combining the two indices ensured that both nutrients and other pollutants from organic and non-biodegradable sourses was efficiently assessed than using only one biotic index.

5.5.4. Integrated Index for River Sosiani

Integrated index for River Sosiani was finally computed from the three indices (Habitat, Macrophytes and Macroinvertebrates) with pollution metrics. This index was also regressed with pollution metrics as the previous indices (Sanchez-Montayo *et al.*, 2010; Yung-Chul *et al.*, 2012; Lyche-Solheim, *et al.*, 2013). Its linear relationship with pollution metrics was the basis that makes it reliable in the assessment of the health of River Sosiani. No station along River Sosiani was evaluated to have surface waters of excellent quality class, since all of them had anthropogenic activities of degradation effect, which was in any of the categories; physical habitat degradation of the riparian zone, physico-chemical water quality degradation, biotic community structure alteration or a combination of them. The study therefore inferred that integration of the indices was able to depict the extent of

River Sosiani health at each sampling site better than a single indicator (Hering *et al* 2006; Hughes *et al.*, 2009; King and Brown 2010) like physico-chemical water quality measurements or biotic indices, since, different sampling stations had different anthropogenic activities, and at different degree of degradation which affected the response of the indicators at different intensity. Therefore, the indices provided a complementary and comprehensive information on ecological status and pressures affecting and therefore, the development of an integrated index to assess River Sosiani health.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1.Conclussion

The physical habitat characteristics of River Sosiani is changing due to anthropogenic activities like human disturbance along the riparian zone, nutrient pollution from farming and municipal waste discharge. This in-turn, affect dominance and richness of biota hence, their response to pollution. Macroinvertebrate orders like Ephemeroptera (Siphlonuridae and Baetidae) and Diptera (Chironomidae and Similiidae) dominated the most polluted sites like Huruma and Maili inne stations with multiple pollution effect. However, macrophyte richness was observed at the upper catchment stations where agricultural activities are basic. The damming effect that create a wetland condition and increasing nutrient enrichment of the water quality seemed to favor macrophyte growth. This physical habitat characteristics described the ecomorphological appearance of the river.

Temporal variation in water quality is also significant along the river and most significantly during the dry season. The water quality parameters indicate high concentrations during dry season than wet season, with strong correlation between the physico-chemical indicators and the sites. Nutrients being high at the agricultural sites like Elegrin and Two Rivers Dam while high BOD levels at sites with municipal discharge like Huruma and Maili inne in both seasons. Spatial variation in water chemistry has an increasing trend from the reference site downstream. Nutrients and organic pollution are however key pollutants along the river channel. Water quality indices reflect the degree of pollution of point and non-point source and water chemistry along the river.

Abundance of vegetation of aquatic, semiaquatic and riverine species changes along TON and TP concentration. Macrophytes responded well to TON concentration, which was generally higher than TP concentration along the river, during the study period. Macroinvertebrates respond to the changing nutrient loads and BOD concentration, with low tolerance to TP that to TON and BOD concentrations. Macroinvertebrate families show low diversity, low evenness and high dominance of pollution tolerant family like Chironimidae and Siphlonuridae which were the dominant taxon in the most polluted sites sampled along River Sosiani. The response of macrophytes and macroinvrtebrates differed at different water quality indicators of pollution.

Pollution metrics for River Sosiani scored maximum at Huruma (most polluted site) and minimum at Cheboen (reference site). Biotic Index for River Sosiani Health differed in response comparing macrophytes and macroinvertebrates. Macrophyte Index for River Sosiani Health recorded a high index value with nutrient pollution than Macroinvertebrate Index for River Sosiani. The indices were however not significantly different at the multiple pollution effect. However, macroinvertebrates were generally more sensitive to pollution than macrophytes.

The metrics had a strong linear relationship with TON, TP and BOD concentration and also, with the developed indices. Integrated index was able to evaluate River Sosiani health by incorporating different human activities at each sampling site, through a combination of the three indices (HIRS, MpIRSH and MinvIRSH) and give an index value corresponding to the extent of degradation along River Sosiani; the basis for assessment of the health of River Sosiani.

6.2.Recommendation

1. Physical habitat characteristic of the riparian zone along River Sosiani demands appropriate conservation measures like monitoring the upper catchment area where cattle-ranching and flower farm is practiced adjacent to the river, with subsistence agriculture along the buffer zone.

2. The efficiency of Huruma sewage ponds when human settlement, agricultural activities and dumping sites are near the riverbank should be a point of concern.

3. The Government of Kenya or through National environmental management authority should monitor polluting sectors, charges levied on pollution and policies formulated and implemented on regulation of the extent of discharge of wastes. Environmental protection laws intrinsically related to river ecosystem may be important at the moment to control the degradation that is currently being practiced.

4. There is need for more assessment of other chemical pollutants such as heavy metals and toxic pollutants. Environmental impact assessment is also very important in evaluation of the large-scale flower-farm and cattle-ranch activities presently practiced along the river. Evaluation of the municipal effect at Huruma sewage treatment plant is also necessary since this was the peak of the effect of pollution. This will also help in policy formulation and hence, the future of the River health at large and the society downstream that are dependent on the River water.

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Appendix 1: Sosiani Flora

FAMILY	SPECIES	STATUS	FAMILY	SPECIES	STATUS
ACANTHACEAE	*Asystasia schimperi* T. Anders	**I**	**ASTERACEAE**	*Crassocephalum crepidioides* (Jacq.) S. Moore	**I**
	Dyschoriste radicans Nees.	**I**		*Crassocephalum manii* (Hook. f.) Milne-Redh	**I**
	Hygrophylla auriculata (Schummach) Heine	**I**		*Crassocephalum montuosum* (S. Moore) Milne-Redh	**I**
	Thurnbergia alata Sims	**I**		*Crassocephalum picridifolium* (DC.) S. Moore.	**I**
ALOACEAE	*Aloe kendongensis* Reynolds.	**I**		*Crassocephalum rubens* (Jacq) S. Moore	**I**
	Aloe volkensii Engl.	**I**		*Dichrocephala integrifolia* O. Kuntze	**I**
AMARANTHACEAE	*Achyranthes aspera* L	**I**		*Emillia coccinea* (Sims.) D. Don	**I**
	Amaranthus spinosa L.	**E**		*Erlangea cordifolia* (Benth) S. Moore	**I**
	Cyathula polycephala Bak.	**I**		*Eupatorium adenophorum* Spreng.	**I**
ANACARDIACEAE	*Rhus natalensis* Klauss.	**I**		*Galinsoga parviflora* Cav. Plate	**I**
	Rhus vulgaris Meickle	**I**		*Gnaphalium luteo-album* L.	**I**
APIACEAE	*Centella asiatica* (L.) Urb.	**I**		*Guizortia scabra* (Vis.) Choiv	**E**
	Coriandrum sativum L.	**I**		*Hirpicium diffusum* (O. Hoffm) Roess.	**I**
	Hydrocotyle sibthorpioides Lam	**I**		*Hoehneria vernonioides* Scweinf.	**I**
	Peucedanum aculeolatum Engl.	**I**		*Laggera elatior* R.E. Fries	**I**
	Torilis arvensis (Huds.) Link	**I**		*Microglossa densiflora* Hook f.	**I**
APOCYNACEAE	*Carrisa edulis* (Forsk.) Vahl	**I**		*Notonia abyssinica* A. Rich	**I**
ARALIACEAE	*Cussonia spicata* Thunb.	**I**		*Pennisetum purpureum* Schummach	**I**
ARECACEAE	*Phoenix reclinata* Jacq.	**I**		*Schkuhria pinnata* (Lam.) O. Kuntze	**I**
ASCLEPIADACEAE	*Gomphocarpus physocarpus* E. Mey	**I**		*Sonchus asper* (L.) Hill	**I**
	Gomphocarpus semilunatus A. Rich	**I**		*Sphaeranthus suaveolens* (Forsk) DC.	**I**
	Kanahia laniflora (Forsk.) R. Br.	**I**		*Tagetes minuta* L.	**I**
ASTERACEAE	*Acmella calirhiza* Del.	**I**		*Tithonia diversifolia* (Hemsl.) a. Gray	**I**
	Ageratum conyizoides L.	**I**		*Vernonia auriculifera* Hiern.	**I**
	Aspilia mossambiscensis (Oliv.) Wild	**I**		*Vernonia galamensis* (Cass) Less.	**I**
	Bidens pilosa L.	**I**		*Vernonia syringifolia* O. Hoffm.	**I**
	Bothriocline somalensis (Oliv & Pers) R. Br.	**I**	**BALSAMINACEAE**	*Impatiens tinctoria* A. Rich	**I**
	Carduus chamaecephala Vatke.	**I**	**BASSELACEAE**	*Basella alba* L.	**I**
	Carduus nyassanus (S. Moore) R.E.Fries	**I**	**BIGNONIACEAE**	*Markhamia lutea* (Benth) K. Schum	**I**
	Cirsium vulgare (Savi.) Ten	**I**		*Spathodea nilotica* Seem.	**I**
	Conyza floribunda Kunth.	**I**		*Tecomaria capensis* (Thunb.) Lindl.	**I**
	Conyza newii Oliv & Hiern	**I**	**BORAGINACEAE**	*Cordia abyssinica* R. Br	**I**
	Conyza stricta Willd.	**I**		*Cynoglossum coeruleum* A. DC.	**I**
	Conyza subscaposa O. Hoffm	**I**	**BRASSICACEAE**	*Brassica oleracea* L.	**I**

FAMILY	SPECIES	STATUS	FAMILY	SPECIES	STATUS
BRASSICACEAE	*Lepidium bonariense* L.	**I**	**CYPERACEAE**	*Fuirena stricta* Steud.	**I**
	Rhaphanus raphanistrum L	**I**		*Juniperus procera* Endr.	**I**
	Sisymbrium officinale (L.) Scop	**I**		*Kyllinga bulbosa* P. Beauv.	**I**
CAESALPINIACEAE	*Acrocarpus fraxinifolius* Wight et Arn	**E**		*Pycreus nitidus* Lam.	**I**
	Ptelolobium stellatum (Forsk) Brenan.	**I**		*Schoenoplectus corymbosus* (Roem & Schult) J. Ray	**I**
	Senna didymobotrya (Fressen) Irwin & Barneby.	**I**	**DIPSACACEAE**	*Dipsacus pinnatifidus* A. Rich	**I**
	Senna occidentalis (L.) Link	**I**	**EUPHORBIACEAE**	*Acalypha fruticosa* Forsk.	**I**
CAMPANULACEAE	*Lobelia aberderica* R.E & C. E. Fries.	**I**		*Acalypha segatilis* Muel.Arg	**I**
CASUARINACEAE	*Casuarina equisetifolia* L.	**E**		*Clutia abyssinica* Jaub & Spach	**I**
CERASTRACEAE	*Maytenus senegalensis* (Lam) Exell.	**I**		*Croton macrostachyus* Hochst ex Ferret et Galinier	**I**
CHENOPODIACEAE	*Chenopodium carinatum* R. Br.	**I**		*Croton megalocarpus* Hutch	**I**
CHLOROPHYCEAE	*Elodea canadensis* Michx.	**I**		*Erythrococca bongensis* Pax	**I**
COMMELINACEAE	*Aeolanthus heliotropoides* Oliv	**I**		*Phyllanthus sepialis* Muel. Arg	**I**
	Commelina Aftricana L.	**I**		*Ricinus communis* L.	**I**
	Commelina beghalensis L.	**I**		*Tragia brevipes* Pax	**I**
	Cyanotis foecunda Hassk.	**I**	**FLACOURTIACEAE**	*Dovyalis abyssinica* (A.Rich) Warb	**I**
	Floscopa glomerata (Schult & Schult) Hassk.	**I**		*Flacourtia indica* (Burm f.) Merr.	**I**
	Murdannia simplex (Vahl.) Brenan	**I**	**LAMIACEAE**	*Achyropspermum schimperi* Hochst ex Briq.	**I**
CONVOLVULACEAE	*Cuscuta kilimanjari* Oliv	**I**		*Fuerstia Aftricana* T. C. E. Fr.	**I**
	Ipomoea batatas (L.) Lam	**I**		*Leonotis ocymifolia* (Burm f.) Iwarsson	**I**
	Ipomoea cairica (L.) Sweet	**I**		*Leucus martiniscensis* (Jacq.) Ait. F	**I**
CRASULACEAE	*Crassula gravinkii* Mildbr.	**I**		*Ocimum kilimandscharicum* Guerke	**I**
	Kalanchoe densiflora Rolfe.	**I**		*Plectranthus barbartus* Andr.	**I**
CUCURBITACEAE	*Cucurmis dipsaceous* Spash.	**I**		*Plectranthus edulis* (Vatke) Agnew.	**I**
	Lagenaria abyssinica (Hook f.) C. Jefftrey	**I**		*Plectranthus sylvestris* Guerke.	**I**
	Momordica foetida Schummach	**I**		*Pycnostachys meyeri* Guerke.	**I**
	Zehneria scabra (L.f.) Sond	**I**		*Salvia nilotica* Jacq.	**I**
CUPRESSACEAE	*Cupressus lusitanica* Mill.	**E**		*Satureia biflora* (D. Don) Benth.	**I**
CYPERACEAE	*Cyperus alternifolius* L.	**I**	**LEMNACEAE**	*Lemna gibba* L.	**I**
	Cyperus laevigatus Makaloa	**I**		*Buddleia polystachya* Fresen.	**I**
	Cyperus rigidifolius Steud.	**I**		*Nuxia congesta* R. Br. Ex Fressen	**I**
	Cyperus strigosum L.	**I**	**LYTHRACEAE**	*Strychnos henningsii* Gilg.	**I**
	Eleocharis radicans (A. Dietr.) Kunth	**I**		*Rotala tenella* Hiern.	**I**
	Fimbristylis complanata (Retz.) Link.	**I**	**MAESACEAE**	*Maesa lanceolata* Forsk.	**I**

FAMILY	SPECIES	STATUS	FAMILY	SPECIES	STATUS
MALVACEAE	*Abutilon mauritianum* (Jacq) Medic	**I**	**PAPPILIONACEAE**	*Phaseolus vulgaris* L.	**I**
	Hibiscus canabinus L.	**I**		*Rhynchosia minima* L.	**I**
	Pavonia urens Cav.	**I**		*Sesbania sesban* (L.) Mill	**I**
	Sida cuneifolia Roxb.	**I**		*Trifolium lugardii* Bullock.	**I**
	Sida ovata Forsk	**I**		*Trifolium semipilosum* Fres.	**I**
MARANTACEAE	*Maranta arundinacea* L.	**I**	**PHYLLANTHACEAE**	*Bischofia javanica* Blume	**E**
MARCHANTIACEAE	*Marchantia polymorpha* L.	**I**	**PHYTOLACACEAE**	*Phytolacca dodecandra* L.' Herrit	**I**
MELIANTHACEAE	*Bersama abyssinica* Fres.	**I**		*Phytolacca octandra* L.	**E**
MENISPERMACEAE	*Cissamperos pareira* L.	**I**	**PINACEAE**	*Pinus patula* Schiede ex Schuldtl & Cham	**E**
	Stephania abyssinica (Quart-Dill & A. Rich) Walp.	**I**		*Pinus radiata* D. Don	**E**
MIMOSACEAE	*Acacia abyssinica* Hochst ex Benth	**I**	**PITTOSPORACEAE**	*Pittosporum viridiflorum* Sims.	**I**
	Acacia lahai Benth.	**I**	**PLANTAGINACEAE**	*Plantago palmata* Hook f.	**I**
	Acacia mearnsii de Willd.	**E**	**POACEAE**	*Andropogon abyssinica* Fressen	**I**
	Acacia melanoxylon R. Br.	**E**		*Arundinaria alpina* K. Schum.	**I**
	Acacia seyal Del	**I**		*Brachiaria brizantha* (Hochst.ex A. Rich) Stapf	**I**
	Acacia xanthophloea Benth.	**I**		*Brachiaria decumbens* Stapf.	**I**
	Albizia gummifera (J. F. Gmel) C.A. Sm.	**I**		*Chloris gayana* Kunth	**I**
MORACEAE	*Ficus thonningii* Blume.	**I**		*Chloris pycnothrix* Trin.	**I**
MUSACEAE	*Musa sapientum* Linn.	**I**		*Cynodon dactylon* (L.) Pers	**I**
MYRTACEAE	*Eucalyptus saligna* Sm.	**E**		*Digitaria scalarum* (Schwienf.) Chiov.	**I**
	Sizygium cordatum Hochst ex Krauss.	**I**		*Digitaria velutina* (Forssk.) P. Beauv.	**I**
	Sizygium guineensis (Willd) DC.	**I**		*Echinochloa pyramidalis* (Lam) Hitch & Chase	**I**
NYMPHAEACEAE	*Nymphaea lotus* L.	**I**		*Eleucine jaegeri* Pilg	**I**
OLEACEAE	*Jasminum abyssinica* DC.	**I**		*Eragrostis chalarothyrsus* C.E. Hubbard	**I**
ONAGRACEAE	*Epilobium hirsutum* L.	**I**		*Eragrostis tuneifolia* (A. Rich) Steud	**I**
	Ludwigia abyssinica A. Rich.	**I**		*Harpachne schimperi* Hochst ex A. Rich.	**I**
	Ludwigia leptocarpa (Nutt.) H. Hara	**I**		*Hyparrhenia filipendula* (Hochst.) Stapf	**I**
ORCHIDACEAE	*Habenaria petitiana* (A. Rich) Dur & Schinz.	**I**		*Hyparrhenia rufa* (Nees.) Stapf	**I**
OXALLIDACEAE	*Oxalis corniculata* L.	**I**		*Leersia hexandra* Sw.	**I**
PAPPILIONACEAE	*Aeschenomene abyssinica* (A. Rich) Vatke	**I**		*Panicum hymeniochilum* Nees.	**I**
	Crotalaria agatiflora Schweinf.	**I**		*Panicum maximum* Hochst ex A. Rich.	**I**
	Glycine wightii (Wight & Arn) Verdc.	**I**		*Pennisetum cladestinum* Chiov.	**I**
	Indigofera homblei Bam. f & Martin	**I**		*Rhyncherytrum repens* (Willd.) C.E. Hubbard	**I**
PAPPILIONACEAE	*Lupinus princei* Harms.	**E**		*Setaria sphacellata* (Schumach) Moss.	**I**

FAMILY	SPECIES	STATUS	FAMILY	SPECIES	STATUS
POACEAE	*Sporobolus pyramidalis* P. Beauv.	**I**	**SOLANACEAE**	*Datura stramonium* L.	**N**
	Zea mays L.	**E**		*Nycandra physalodes* (L.) Gaertn.	**N**
PODOCARPACEAE	*Podocarpus gracilior* Pilger	**I**		*Physalis peruviana* L.	**E**
POLYGONACEAE	*Oxygonum sinuatum* (Meisn.) Dammer.	**I**		*Solanum aculeastrum* Dunal.	**I**
	Polygonum pulchrum Blume.	**I**		*Solanum hastifolium* Dunal.	**I**
	Polygonum salicifolia Willd.	**I**		*Solanum incanum* L.	**I**
	Polygonum setosulum Meissn.	**I**		*Solanum mauritianum* Scop.	**I**
	Polygonum strigosum R. Br.	**I**		*Solanum nigrum* L.	**I**
	Rumex bequaertii De. Willd.	**I**		*Solanum sessilistellatum* Bitter	**I**
POTAMOGETONACEAE	*Aponogeton stulmanii* Engl.	**I**	**STERCULIACEAE**	*Dombeya torrida* (J.F.Gmel) P. Bamps.	**I**
	Potamogeton schweinfurthii A. Bennet	**I**		*Triumfetta tomentosa* Boj.	**I**
PROTEACEAE	*Grevillea robusta* A. Cunn ex R.Br	**E**	**TILIACEAE**	*Grewia similis* K. Schum	**I**
RANUNCULACEAE	*Ranunculus multifidus* Forsk.	**I**		*Sparmannia ricinocarpa* (Eckyl & Zey) Kuntze	**I**
RHAMNACEAE	*Rhamnus prionoides* L'Herit.	**I**		*Triumfetta rhomboidea* Jacq.	**I**
	Scurtia myrtina(Burm f.) Kurz.	**I**	**TYPHACEAE**	*Typha domingensis* Pers.	**I**
ROSACEAE	*Alchemilla cryptantha* Steud ex A. Rich	**I**		*Typha latifolia* L.	**I**
	Alchemilla rothii Oliv. R.E & C. E. Fries.	**I**	**URTICACEAE**	*Urtica massaica* Mildbr.	**I**
	Eriobotrya japonica (Thunb.) Lindl.	**E**	**VERBENACEAE**	*Clerodendron johnstonii* Oliv.	**I**
	Haggenia abyssinica (Bruce) J.F. Gmel.	**I**		*Lantana camara* L.	**I**
	Prunus Aftricana(Hook f.) Kalkm.	**I**		*Lantana trifolia* L.	**I**
	Rubus apetala Poir.	**I**		*Verbena bonariensis* L.	**I**
	Rubus steudneri Schweif.	**I**	**VITACEAE**	*Cyphostemma adenocaule* (A. Rich) Willd & Drum	**I**
RUBIACEAE	*Galium scioanum* Chiov. Plate	**I**		*Cyphostemma orondo* (Gilg & Bened) Desc	**I**
	Pavetta abyssinica Fressen.	**I**		*Rhoicissus tridentata* (L.f.) Wild & Drum.	**I**
	Psychotrya mahonii L. Wright	**I**	**ZYGNEMATACEAE**	*Spyrogyra*	**I**
	Richardia braziliensis Gomez	**I**			
	Rubia cordifolia L.	**I**			
	Spermacose pusila Wall	**I**			
	Vangueria infausta Burch.	**I**			
	Vangueria tomentosa Hochst.	**I**			
RUTACEAE	*Teclea nobilis* Del.	**I**			
	Toddalia asiatica (L.) Ram	**I**			
SAPINDACEAE	*Dodonea viscosa* (L.) Jacq	**I**			
SCHROPHULARIACEAE	*Craterostigma pumilum* L.	**I**			

Appendix 2: Physical, Chemical and Biological indicators of water quality

	Indicator	Parameter measured	Possible responses to disturbance
Biological	• Birds • **Macro-invertebrates** • Amphibians • Zooplankton • Algae • **Vegetation** • Microbes	Community and/or population structure, diversity, species richness, health of individuals	Shift in species composition, community structure. Disturbance-tolerant species dominance
Chemical	• **pH** • Turbidity • **Dissolved oxygen** • **Phosphorous and** • **Nitrogen concentration** • Metals • Pesticides • Dissolved organic carbon • Major ions • Cyanotoxins	Acidity, water clarity, nutrient status of water, pesticides, metals, hydrocarbons, salinity, organics	Change in water pH, eutrophication and algal bloom, anoxic water and/sediments Change to biogeochemical cycling Toxic responses by organisms
Physical	• Water depth • **Temperature** • Hydrology • Sediment composition • Decomposition • Structure	Water availability and permanence, water recharge and discharge capabilities, peat accumulation, seasonality of changes in water depth	Changes in water storage or discharge Changes to ground or surface water connectivity Increased or decreased decomposition

Appendix 3: Assessment methods and indices used in of water quality evaluation

Assessment methods	**Objective**	**Spatial scale/ Stream type**	**Taxonomic level**	**Scale of measurement**	**Complexity**
Saprobic indices	Organic pollution	High/ None	Species	Uni- dimensional	Simple
Diversity indices	Water quality	High/ None	Species	Uni- dimensional	Simple
Biotic indices	(Organic) pollution	High/ None	Higher taxa	Uni- dimensional	Simple
Multimetrics	System quality	High/ Ecoregion	Higher taxa (species)	Uni- dimensional	Moderate
Physico-ecological assessment	Riparian quality	High/ None	-	-	Moderate
Catchment scale assessment	Land use effect	Moderate/ None	Higher taxa	Uni- dimensional	Moderate
Ecosystem components assessment	System quality	Moderate/ Main types	Species and higher taxa	Uni- dimensional	Moderate
Assemblage/communit y assessment	System state	Low/ Stream types	Species	Multi- dimensional	High

Appendix 4: Types of habitat assessment and approaches in habitat assessment

Assessment type	Approach	Spatial scales addressed	Example
Broad scale assessment	Involves delineation of the stream system into shorter segments, types or reaches based on physical characteristics. Initial division is often based on features such as channel slope, channel pattern, geology, surrounding land use and/or hydrological regime identified from map sources and/or historical data.	Drainage basin to reach level	Rosgen classification (Rosgen, 1996) River habitat survey (Fox *et al*., 1996) Reconnaissance level survey (Thorne & Easton, 1994) Habitat mapping (Maddock & Bird, 1996)
Microhabitat assessments	Uses analysis of small scale variables such as substrate, cover, water depth and current velocities to identify the quantity and quality of the physical habitat available for selected target species	Reach to patch scale	PHABSIM (Bovee, 1996) Bioenergetics models (Hill & Grossman, 1993)
Empirical habitat models	Regression models are developed to predict biological characteristics based on measurement of existing physical features	Reach to patch scale	Habitat quality index (Binns & Eiserman, 1979) HABSCORE (Milner *et al*., 1985)