AN ASSESMENT OF WETLAND INFLUENCE ON WATER QUALITY OF RIVER MERERONYI, KENYA.

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A thesis Submitted to the Graduate School in partial fulfillment of the requirement for the Degree of Master of Science in Limnology of Egerton University.

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DECLARATION AND RECOMMENDATIONS

DECLARATION:

This thesis is my original work and has not been presented wholly or partially for a degree, diploma or any other award in Egerton University or any other university known to me.

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RECCOMMENDATIONS:

This work has been presented with our approval as university supervisors.

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In a special way, I acknowledge the patience and inspiration of my husband Dancun Onyango, my son Chris Onyango and my daughter Graca Onyango, thank you and God bless you all.

DEDICATION

I dedicate this work to my son Chris who attended coursework but was never a registered student, my daughter Graca who attended field work but was never a researcher, my husband Dancun who was the donor.

ABSTRACT

An investigation to assess the influence of a natural wetland in the middle reach of River Mereronyi , Kenya, on the river water quality was carried out between May and June, 2008. The aim of the study was to evaluate the effect of this particular wetland on nutrients (Nitrogen and Phosphorus) and removal and trapping of coliforms (*E. coli,* total coliforms) in the river water.

Water samples were collected weekly using acid washed plastic bottles, while sediment samples were collected using a corer. During every sampling session; temperature, conductivity, Dissolved Oxygen (DO) and pH were measured *in situ* using Wissensschaftlich-Technische Werkstätten (WTW) microprocessor meters and probes. River discharge was estimated using velocity area method.

In the laboratory nutrients; nitrogen and phosphorous were determined using colorimetric methods, while bacteriological analyses were done using pour plate technique and Most Probable Number method. Plant productivity was measured using harvest method, where a 0.25×0.25m quadrat was used to demarcate the plots and plants harvested just above the roots. The concentration of TN and TP in water and sediment was determined using the Kjeldahl digestion method. Data was analyzed using a Statistical Package for Social Sciences (SPSS version 12) where comparison of means of different variables was performed using Analysis of Variance (ANOVA). The relationship between the concentration of different variables in water and sediment samples was analyzed using simple linear regression analysis. Student's t-test was used to determine the significant difference between selected variables at the wetland inlet and outlet.

Water temperature differed significantly between the sites during the study period ($t = 2.054$, df $=54$, $p < 0.05$). Mean river discharge was 4.9 ± 2.2 m^3s^{-1} at the wetland inlet and 6.7 ± 2 m^3s^{-1} at the wetland outlet. The papyrus standing biomass was 21.84 tonnes/ha^{-1} . There was a significant negative relationship between phosphorus in sediment and that in plants with correlation coefficient of $r = - 0.95$. A significant positive relationship between total nitrogen in water and in plants with a correlation coefficient of $r = 0.91$ was also observed in this study. The results showed removal efficiencies by the wetland of 20% for ammonium, 32.7% for nitrate-nitrogen, 61.8% for Soluble Reactive Phosphorus, 57% for total phosphorus and 45.85% for total nitrogen. The highest number of *E. coli* and total coliforms of 516 MPN/100ml and 390 No/100ml was recorded in a disturbed site 3 (S3) within the wetland. There was reduction of SRP, NO_3, TN and NH_4 in water between the wetland inlet and wetland outlet. This study recommends that the wetland should be reclaimed by WRMA and NEMA together with the local community.

TABLE OF CONTENTS

LIST OF PLATES

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

APHA	American Public Health Association.
EAEN	East Africa Environmental Network
ADC	Agricultural Development Cooperation
FC	Faecal Coliforms
EC	Electrical Conductivity
TDS	Total Dissolved Solids
D	Depth
V	Velocity
W	width
SPSS	Statistical Package for Social Sciences
SE	Standard Error
NEMA	National Environment Management Authority
WRMA	Water Resource Management Authority
µS/cm	Micro Siemens per centimeter
Temp	Temperature
m^2	Square metre
Dmm^{-2}	Dry mass per square metre
$dm\ gm^{-2}$	Dry mass in grams per square metre
$dm^{-1}m^2d^{-1}$	Dry mass per square metre per day
$gm^{-3}s^{-1}$	Grams per cubic meter per second
gm^{-2}	Grams per square metre
mgL^{-1}	Milligram per litre
mgg^{-1}	Milligram per gram
kgd^{-1}	Kilogram per day
ms^{-1}	Metres per second
Ls^{-1}	Litres per second
km	Kilometre
km^2	Square kilometre
mm	Millimetre
ml	Millilitres
^oC	Degree centigrade

wt	Weight
ha	Hactares
m.a.s.l	Metres above sea level

Formulas

H_2SO_4	Sulphuric acid
NaOH	Sodium Hydroxide
NH_4OH	Ammonium Hydroxide
NH_4-N	Ammonium- nitrogen
NO_3 - N	Nitrate –nitrogen
NO_2 -N	Nitrite -nitrogen

DEFINITION OF TERMS

Bog	An area having a wet spongy, acid substrate composed chiefly of sphagnum moss and peat in which characteristic shrubs and herbs and some times trees.
Fen	Inland marsh; an inland area of low-lying marshy land, now often drained and cultivated because its nutrient rich soil.
Floodplains	A nearly flat plain along the course of a stream or river that is naturally subjected to flooding.
Swamps	A seasonally flooded bottom and with more woody plants than a marsh.
Biodiversity	Variation of life forms within a given ecosystem, biome or the entire earth.
Arthropogenic	Effects, processes or materials derived from human activities, as those occurring in the biophysical environment.
Eutrophication	An increase in the concentration of chemical nutrients in an ecosystem to an extent it increases the primary productivity of the system.
Sedimentation	The process of depositing sediment.
Turbidity	Measure of the degree to which the water looses its transparency due to the presence of suspended particles.
Biodegradable	Capable of being broken down especially into innocuous products by the action of microorganisms.
Biomass	Mass of living biological organism in a given area or ecosystem in a given time.
Allochthonous	Not indigenous, acquired, nutrients that originates from a distant.
Autochthonous	Indigenous material that was formed in its present position.
Mineralization	The release of organic compounds during decomposition.
Adsorption	Accumulation of atoms or molecules on the surface of material.
Desorption	Phenomenon whereby a substance is released from or through a surface.
Nutrients	A chemical that an organism needs to live and grow or a substance used in an organism metabolism which must be taken from the environment.
Corliforms	The name of a test adopted in 1914 by the Public Health Service for the Enterobacteriaceae family.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Until recently, wetlands have been regarded as mosquito-infested, mucky, dangerous and unhealthy places. As a result of these misconceptions, a large number of wetlands have been destroyed worldwide over time. Wetlands occupy an ecological position between terrestrial and aquatic environments and they play an important role in coupling the terrestrial to the aquatic ecosystem.

According to the Ramsar Convention (1971), wetlands are "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt including areas of marine water, the depth of which at low tide does not exceed six meters." Davies and Claridge (1993) stated that wetlands mean different things to different people and this variety of wetland definitions and classifications does exist. This study adopts wetlands definition of Mitsch and Gosselink (1993) with three inherent features included where wetlands;

1 Are distinguished by the presence of water, either at the surface or within the root zone.
2 Have unique soil conditions that differ from adjacent uplands.
3 Support vegetation adapted to the wetland conditions (hydrophytes) and conversely characterized by absence of flood intolerant vegetation.

Wetlands are estimated to occupy nearly 6.4% of the earth's surface, where 30% of the total cover is made up of bogs, 26% fens, 20% swamps and 15% flood plains (Anonymous, 1997).

Wetlands have been shown to posses enormous potential for maintaining the quality or purifying water as it passes through them. Kadlec (1985) stated that all water quality parameters are altered by passage through wetlands. Attributes that make wetlands perform water quality purifying function include: reduction in stream velocities within wetlands leading to sediment deposition, anaerobic and aerobic processes, which are responsible for the transformation and removal of nutrients from the water column. High rates of plant productivity within many wetlands lead to high rates of mineral uptake by the vegetation and burial of dead plants. Other attributes of wetlands include: diversity of **decomposers and decomposition processes that convert pollutants into harmless compounds. Also large contact area between water and sediments** promotes the adsorption of pollutants onto the sediments, hence accumulation of organic peat within wetlands leading to burial of chemicals. The lacustrine wetlands may serve as refugia for indigenous fishes, which may reduce predation, because the low oxygen conditions that prevail in many wetlands limit exploitation by the predators.

Wetlands play two major roles in water supply; recharging ground water aquifers and maintenance of surface waters. Variation in factors such as soil and geological conditions, determines the relationship between wetlands and ground water. This inter-relationship between surface and ground water is affected by increase in water abstraction from the system directly impacting on the availability of water supplies. According to Constanza *et al.,* (1989), wetlands are 75% more valuable than lakes and rivers, 15 times more valuable than forests and 64 times more valuable than grasslands and rangelands. Kenya's wetlands are among the country's most important resources for socio-cultural and economic development. The encroachment of wetland especially those associated with river delta poses a threat of severe ecological changes of the systems. Wetlands provide a sanctuary for flora and fauna particularly rare plants and migratory bird species resulting in high biodiversity. Therefore, wetland provides valuable resources that constitute the basis for both present and future economic development.

These constitute 3% of the country's total surface area, yet they account for over 95% of the water used for domestic, industrial and agricultural purposes (EAEN, 1999). River Mereronyi under study drains extensively cultivated highlands, pastures, settlement areas, wetlands and cultivated plains before it flows into Lake Elementaita. In the headwaters, some areas have been turned into farmlands while others still have natural vegetation. Cultivation in the middle reach has been kept minimal due to steep terrain except in areas with free access to the river, where the impact is intensive. Increased use of fertilizers for agriculture contributes significantly to non-point pollution through run-off (Kivaisi, 2001). However, despite the large wetland along the River Mereronyi, water quality in the lower reach is degraded by anthropogenic activities such as cattle grazing, intensive cultivation along the river and washing of clothes.

1.2 Statement of the Problem.

Most rivers are facing the problem of eutrophication and increased sedimentation due to population increase, which has resulted to conversion of river catchment into human settlements and farmlands. River Mereronyi is an example of such an aquatic ecosystem adversely affected by human activities as shown in Plate 1. River Mereronyi wetland is **also facing a threat of** destruction by the surrounding communities hence interfering with its natural function as a water purifier. The wetland is currently receiving non-point pollutants such as nutrients and pathogens among others emanating from the anthropogenic activities within the catchment. These activities have led to water quality deterioration downstream. Besides this, the natural wetland vegetation has been replaced by crops and exotic trees which are not wetland plants hence compromising its natural water quality function. The area covered by the wetland vegetation has been reduced through wetland destruct No. 119/3ion by human activities therefore reducing its efficiency in water treatment. Comparing the area in 1974 (area 1.8km^2) and 1997 (0.56km^2) using survey of Kenya, sheet No. 119/3 Nakuru, approximately 70% of the wetland has been destroyed. Information on the influence of human activities on the functions of this wetland is lacking. Therefore, this study forms the basis towards understanding the water quality function of River Mereronyi wetland and provide recommendations for future areas of focus towards management of the system for development.

Plate1: Some of the human activities in the upper reach of Mereronyi catchment showing human settlement and farming activities

1.3 Objectives

1.3.1Overall Objective

The broad objective of this study was to evaluate the influence of river Mereronyi wetland on surface water quality.

1.3.2 Specific objectives

1 To analyze the spatio-temporal variation of selected physical-chemical variables of the water and sediments in river Mereronyi wetland.

2 To compare the relationship between total nitrogen and total phosphorus in the water, sediments and plants, of the river Mereronyi wetland, to act as an indicator for nutrient exchange.

3 To determine the nutrient mass balance and removal efficiencies of the river Mereronyi wetland.

4 To assess the variation in concentration of coliforms in selected sites along the river Mereronyi wetland.

1.4 Hypotheses

$H_0$1: There is no significant variation between selected physical-chemical variables along the river Mereronyi wetland.

$H_0$2: There is no relationship between concentrations of phosphorus and nitrogen in surface water, sediment to that in plants.

$H_0$3. River Mereronyi wetland has no significant influence on nitrogen and phosphorous removal.

H_0 4: There is no variation on the concentrations of coliforms in water samples collected at different selected sites along the river Mereronyi wetland**.**

1.5 Justification

Wetlands are very important resources and their protection ought to be emphasized with respect to their water quality function such as indicated by lowering of water turbidity as illustrated in Plate 2. Pollutant loads into river Mereronyi continue to accumulate with increasing human population and activities in the catchment areas indicated by increase in turbidity Plate 3a. River Mereronyi drains into Lake Elementaita which is a Ramsar site. Overexploitation and destruction of wetland vegetation curtail the filter function of **wetlands as nutrients and sediments are** carried to the receiving lake ecosystems. The lake is an important habitat for flamingoes and other water birds, hence making it an important tourist attraction site. Owino *et. Al.*, (2001) observed that Lake Elementaita lacked macrophytes except. *Typha* stands near the inflow of the hot springs at the South East corner of the lake. Lack of macrophytes around Lake Elementaita contributes to increased nutrient load from the upper catchment and result in poor lake water quality. Conservation of wetlands within the catchment like Mereronyi will result in reduction of nutrient loading into the lake with subsequent improvement in lake water quality.

River Mereronyi wetland is one of those aquatic systems in Kenya with limited scientific information. Wetlands are known to improve the water quality as it passes through them as shown in Plate 3b. River Mereronyi wetland is expected to improve the quality of water that passes through it. However, data is lacking to justify its role as a water purifier. Therefore acquisition of information on the influence of the wetland on water quality is crucial. However, most wetland research in Kenya has concentrated on large lacustrine wetlands of the Rift valley, coast and Lake Victoria as reported by Thenya, (2001). Limited research has been carried out on riverine wetlands, since they are regarded as having minimal use and effect in maintenance of water quality of the systems. It is therefore the principal aim of this study to assess the influence of the river Mereronyi wetland on its water quality downstream.

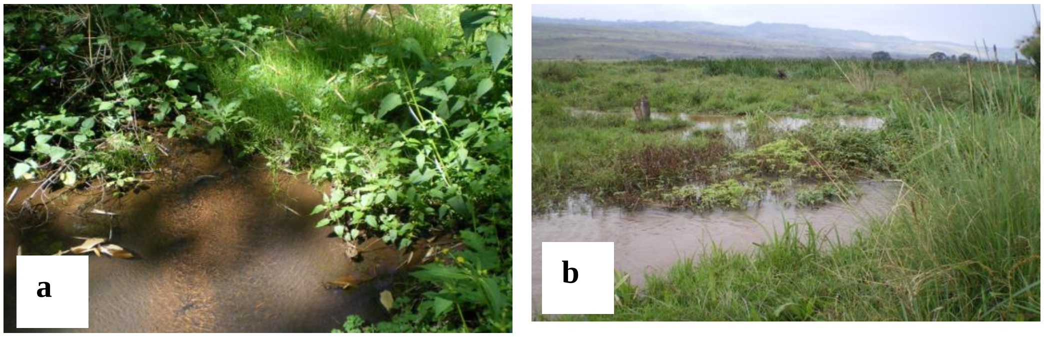


Plate 2: River Mereronyi with minimal anthropogenic disturbance (a) while (b) represents a site with deteriorated water quality indicated by increase in turbidity.

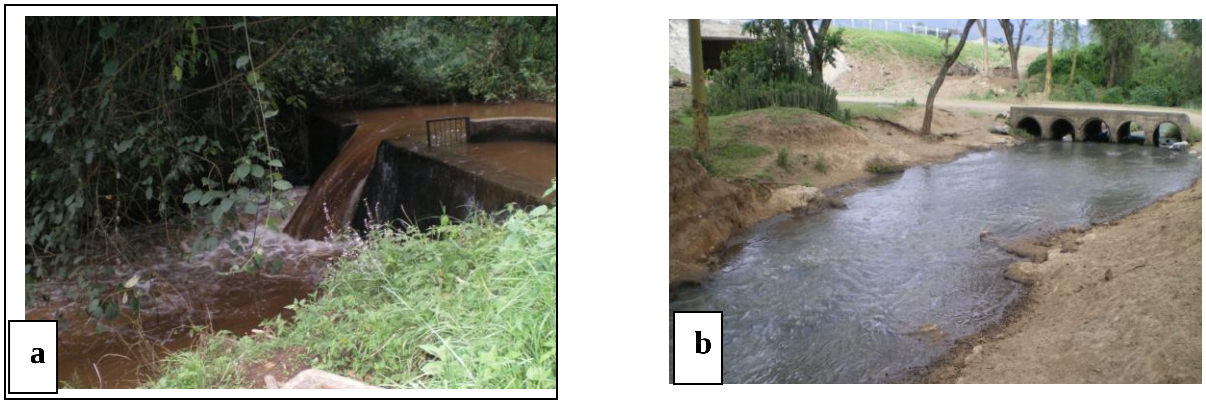


Plate 3: Turbid water that has not passed through a wetland going to Mereronyi treatment plant in Nakuru (a) compared to less turbid water after passing through the river Mereronyi wetland (b).

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Wetlands are capable of reducing a range of pollutants such as organic matter, suspended solids, nutrients and pathogens (Rousseau, 2005). However, the use of wetlands for nutrient removal remains controversial, making it difficult to extrapolate results obtained from one wetland to another. This is because each wetland has its own unique properties depending on its type and location (Hammer and Knight, 1994; Kadlec and Knight, 1996). Wastewater containing organic biodegradable matter and non-biogradable inorganic chemicals are frequently discharged into aquatic ecosystems including natural wetlands. This unregulated practice result in increased concentration of nutrients, sediments and micro-organisms in water which is then considered unsuitable for human consumption as well as agricultural activities (Kivaisi, 2001). Inputs that exceed wetland assimilative capacity result in increased nutrient bioavailability and consequently changes in ecological function, where the wetland becomes a nutrient source rather than a sink.

2.2 Wetland vegetation and productivity in natural wetlands

Wetland vegetation comprise of aquatic macrophytes; mainly emergent, submerged and floating types. In comparison to terrestrial vegetation, emergent macrophytes are unique in that they have the ability to transport oxygen from the atmosphere to the roots. The high productivity of macrophytes accompanied by increased nutrient uptake make these plants act as stores of nutrients. Eventually, the nutrients are recycled into the system once they die through the processes of leaching; decomposition and mineralization (Kansiime and Nalubega, 1999). The ability of plants to remove pollutants has been demonstrated by Kadlec and Knight, (1996) with the most effective ones being *Typha latifolia* and *Phragmites australis*,, *Eicchornia crassipes* and *Phragmites spp* for heavy metals (Anonymous, 1997) and *Eleochharis rotella*, *Scirpus valadis* and *Polygonum spp* for iron removal.

Cyperus papyrus is one of the largest emergent aquatic sedges, common in tropical wetlands both in lotic and lentic systems. Its distribution is largely restricted to East and Central African wetlands where it dominates wetland areas. The wetland along Mereronyi is dominated by *Cyperus papyrus* plants which grow in permanently inundated sites. The **standing aerial biomass of the plant depends on the nutrients concentrations in the interstitial waters**

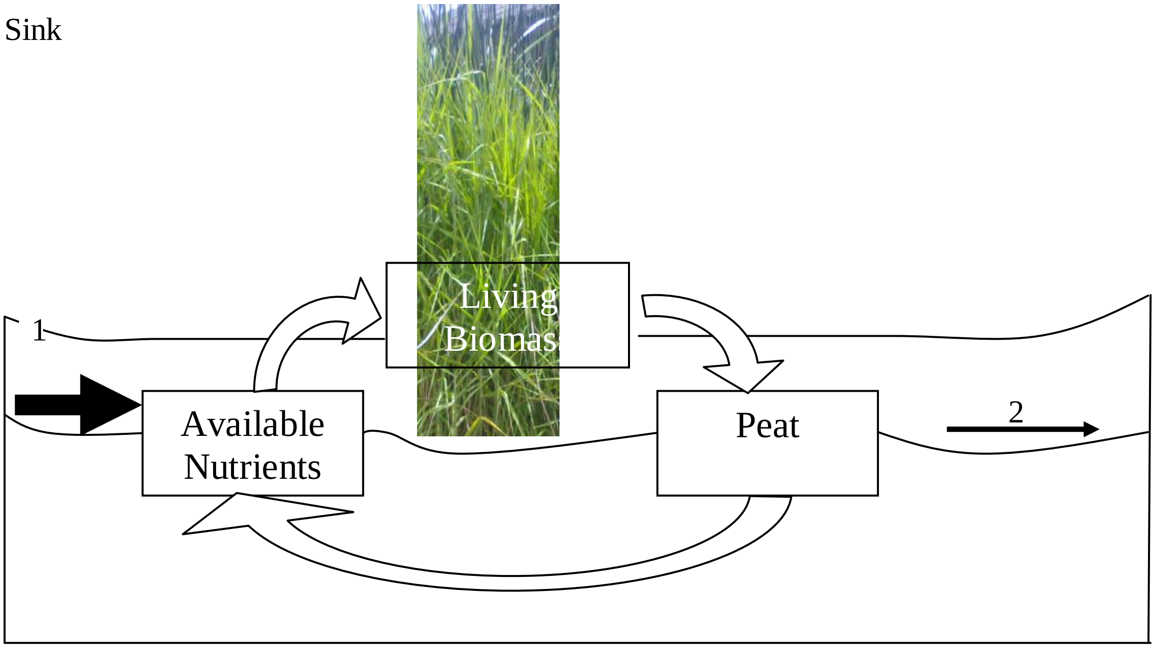
(Kipkemboi *et al.*, 2002). In nutrient rich zones, papyrus are characterized by thick and tall culms with dark green umbels while in nutrient deficient zones, they are characterized by yellowish-green umbels (Kansiime and Nalubega, 1999). Chale (1987) reported high nutrient content in plant parts (culm and umbel) with aerial biomass of 4955gm^{-2} in papyrus swamp in Kahawa in Kenya. These observations were attributed to waste water discharges into the swamp. In Nakivubo swamp in Uganda, the highest aerial biomass was 5844gm^{-2}, which was obtained from papyrus and *Miscanthidium*, plants, growing in the main path of wastewater (Kansiime and Nalubega, 1999). Kipkemboi *et al.,* (2002) observed that the above ground biomass of papyrus in natural wetlands not receiving waste water around Lake Victoria was much lower (1983-2862g dry wt m^{-2}) compared to (3673-6255g dry wt m^{-2}) those receiving waste water.

Since nutrients taken up by papyrus have been shown to return to the aquatic system when the plants die, then periodic harvesting of shoots is one of the management options for nutrient removal from the system. For natural papyrus swamps to maintain a sustainable yield, a harvest interval of 9-12 months has been recommended by Jones (1991) for Eastern Africa.

2.3 Wetlands as nutrient Sink and/or Source

Human intervention in nutrient cycles in tropical Africa may be the result of enrichment in surface waters in the region (Smaling, 1993). The enrichment may originate from runoff from agricultural areas, domestic and industrial wastes among others. Wetlands can act as sinks and/or sources of nutrients to the downstream or adjacent ecosystems. Wetlands are considered sinks if nutrient inputs are greater than outputs as illustrated in (Figure 1a), while they become sources if they can export more nutrients to downstream ecosystem than could occur without the wetland (Figure 1b). Nutrients trapped in the wetland compartments may occur in dissolved forms in water or bound and deposited in peat or sediment and eventually be exported to the nearby water bodies. Sediments act as a platform for nutrient sink or source, for example they can be important phosphorus source in systems that have ceased to receive external loads (Kansiime and Nalubega, 1999). Nutrient sources are either allochthonous or autochthonous or both, from biodegradation and stabilization of settling matter. These processes can yield nutrients that would sustain primary productivity in the adjacent water bodies. However, when nutrient uptake by plants is higher than the amount released at the soil-water interphase, then the wetland acts as a source as illustrated in (Figure. 1b).

a) Sink



b) Source

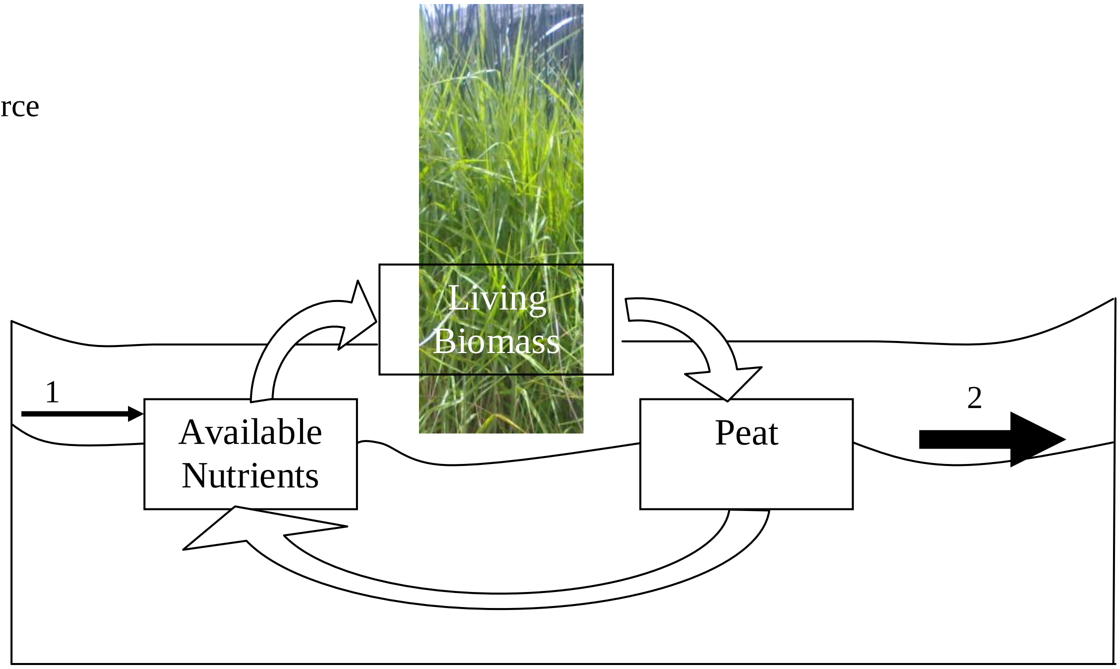


Figure 1: Wetland as a nutrient sink (a) and wetland as a nutrient source (b) (modified from Mitsch and Gosselink, 2000)

N.B 1and 2 represents nutrient inflow to the wetland and outflow from the wetland.

The sizes of the arrows corresponds to the quantity of nutrients getting in (1) or out (2) of the wetland.

2.3.1 Nutrient transformation and removal in wetlands

Nutrients support and sustain the growth of wetland vegetation, which converts inorganic chemicals to organic materials. Nutrient removal is a very important regulatory function of wetlands since it results to slowing eutrophication progression, resulting to good water quality for human consumption and for ecological integrity of the receiving water bodies.

Nitrogen can be present in water in both organic and inorganic forms. The organic form is associated with decaying plant and animal matter, while inorganic form is present as ammonium, nitrate and nitrite ions from the intra-system cycling. There are various anaerobic and aerobic processes which take place within wetlands including; nitrification, denitrification and mineralisation which are responsible for the nitrogen transformation (Anonymous, 1997). Organic nitrogen is converted into ammonia both in aerobic and anaerobic conditions by ammonifying bacteria. However, adsorption of ammonium to the soil is not homogenous and is related to organic content of the sediment (Kadlec and Knight, 1996). The NH_4-N can either be incorporated into the biomass or transformed to NO_3-N via NO_2-N by nitrification process which occurs in aerobic conditions at an optimum temperature of 30-35 ^{o}C (Kansiime and Nalubega, 1999). A soil zone with redox potential >200mv is considered aerobic (Wetzel, 2001) and will support nitrification processes. Ammonia in water is present primarily as NH_4^+-N and as undissociated NH_4OH. The proportions of NH_4^+ -N and NH_4OH are dependent on dissociation dynamics which are governed by pH (6-9.5) and temperature.

Another important nitrogen transformation process is denitrification. Anaerobic conditions in the water logged wetland soils facilitates denitrification process (Verhoeven and Meuleman, 1999), where organisms oxidize organic matter and use nitrate as an electron acceptor resulting to production of nitrogen gas. This leads to loss of nitrogen from the system. Anaerobic bacteria function most efficiently at neutral pH and low redox potential values < -200mv. Toet (2003) found out that nitrogen removal from the water column can be as a result of sedimentation to deeper sediment (Figure 2). The fate of nitrogen is also determined by seepage to ground water. Organic nitrogen incorporated in detritus in a wetland may eventually become unavailable for deep sediment nutrient cycling through the process of peat formation and burial (Kadlec and Knight, 1996).

Phosphorus enters into aquatic environment through several ways which include; weathering of rocks containing phosphorus, agricultural and urban drainage, **decomposition of organic matter** and atmospheric dust. Phosphorus is present in different forms in water and sediment such as dissolved phosphorus, solid mineral phosphorus and dissolved organic phosphorus (Kadlec and Knight, 1996). Phosphorus exchange between water and sediment is mainly a matter of adsorption-desorption which is influenced by bioturbation, sediment re-suspension, pH, redox potential, iron and calcium content. When Dissolved Oxygen (DO) is less than 2mgL^{-l} desorption process takes place, while adsorption takes place when DO is more than 2mgL^{-l} and pH is in the range of 5-6. The availability of calcium influences phosphorus transformation through adsorption by calcium carbonate which precipitates in colloidal form as calcium phosphate. The most important physical characteristics that affect phosphorus load in water bodies are sediment particle size and its distribution, compaction and porosity, density of particles, mixing depth as well as organic matter and oxygen concentration (Lijklema, 1986). Wetlands have a large area of contact between water and sediment which promotes the adsorption of phosphorus onto certain adsorption sites which once occupied there is no further adsorption (Kadlec, 1985). Phosphorus can be removed from the system through several mechanisms; harvesting above ground biomass, since there is no process to eliminate phosphorus by transforming it into volatile substances equivalent to denitrification for nitrogen. The accumulation of organic peat within many wetlands can also result to burial of phosphorus. Another way which phosphorus can be removed is through outflows either as surface, subsurface or both from the wetland, as illustrated in Figure 2.

2.3.2 Role of wetland in pathogen removal

The role of wetlands in removal of pathogens was reported by Gersberg *et al.,* (1987), where they obtained an artificial wetland removal efficiency of 99.1%. Reduction of coliforms was also reported by Toet, (2003), where it was noted that, presence of emergent macrophytes generally had a positive effect on the removal efficiency of coliforms in wetlands. Factors that are considered to affect negatively the survival of pathogens in wetlands include sedimentation, aggregation, inactivation by ultra violet light, alkaline pH, exposure to biocides excreted by plants, adsorption to organic matter, grazing by protozoa and attack by lytic bacteria and viruses (Lijklema *et al.,*1987; Gersberg *et al.,*1989*).*

Coliforms are known to act as universal water quality indicator organisms because they can easily be detected, have a definite faecal origin, excreted in large numbers by animals (Flanagan, 1992). However, coliform organisms in water do not carry the same degree of **feacal** significance, except *Escherichia coli (E. coli)*, which appears to be exclusively of feacal origin. Since coliform bacteria can be detected in small numbers; they form the most sensitive and specific tests for detecting excretal contamination in water. Study of coliforms in water may be of value in determining whether the pollution has been severe enough to render the water potentially hazardous

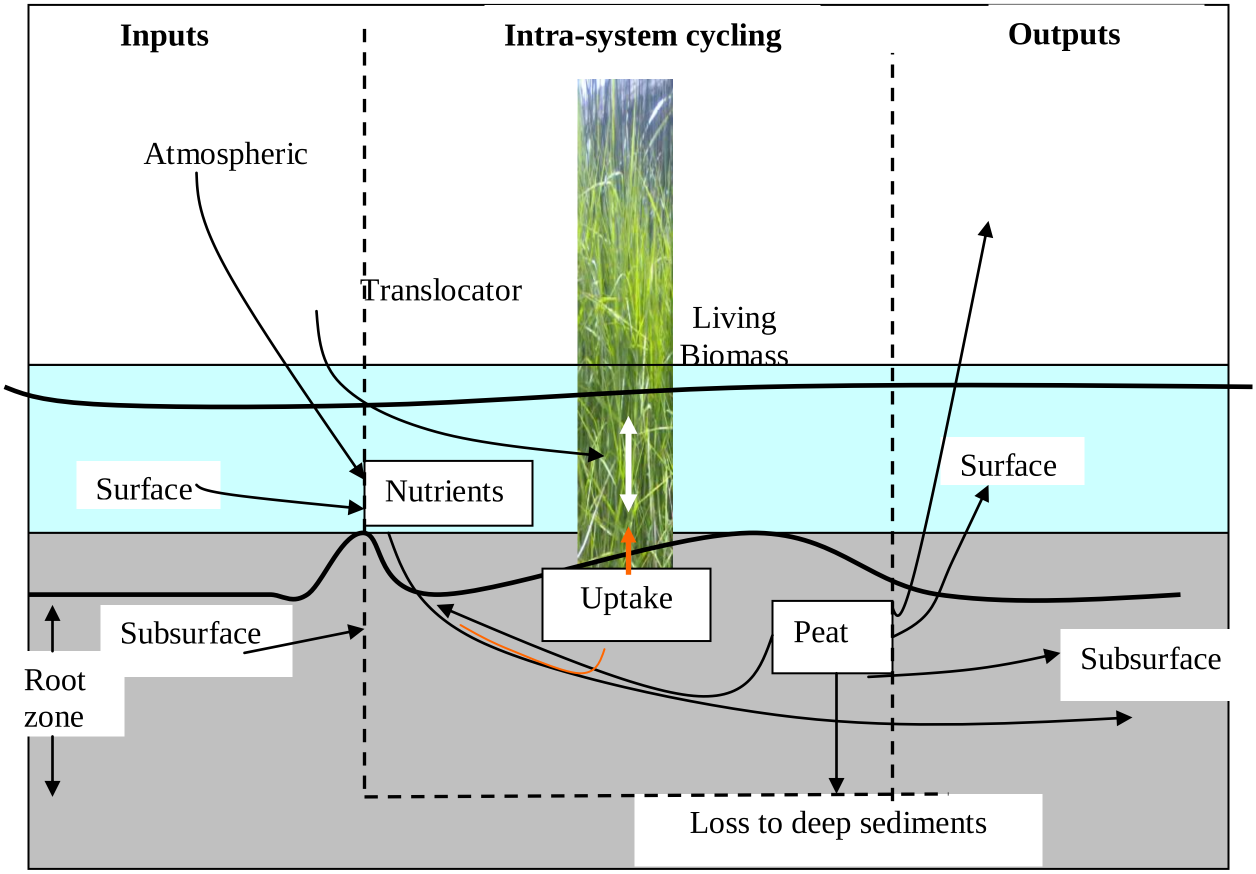


Figure 2: General nutrient inputs, pathways, intra-system cycling and output mechanisms in wetlands *(modified from Mitsch and Gosselink, 2000)*

Wetlands are known to offer a suitable combination of physical, chemical and biological processes for the removal of pathogens. The physical processes include mechanical filtration, exposure to ultraviolet and sedimentation, while chemical processes include mechanical oxidation, exposure to biocides excreted by plants and absorption by organic matter (IWA, 2001). Biological removal mechanisms include antibiosis, predation by nematodes and protists, attack by lytic bacteria and viruses, and natural deaths (Gersberg *et al.*, 1989). Microbial content in wastewater is known to reduce after being discharged into wetlands, so long as there is sufficient distance covered and time for the water to flow through the wetlands. However, their survival depends on the type of macrophytes present in the wetland; for example in Nakivubo swamp in Uganda, it was observed that *Miscanthidium violaceum* had a lower removal capacity of coliforms than *Cyperus papyrus* (Kansiime and Nalubega, 1999).

2.3.3 Role of wetlands in sediment removal

Sediments are made up of three primary components; organic matter in various stages of decomposition, particulate mineral matter, inorganic component of biogenic origin and input from fluvial deposits. Sediments bound in benthic waters are sorted according to particle size depending on the water movements. A gradient of substrate particle sizes changes with water velocity, and thus reduction of stream velocity within wetlands leads to sediment deposition (Anonymous, 1997). Kadlec (1994) presented data on the sediment trapping efficiencies of 13 natural and artificial wetlands, whose mean trapping efficiency was over 69% with six of the wetlands having a trapping efficiency of at least 90%. Anonymous (1997) cautions that though, wetlands have great potential for water quality maintenance or purification roles, lack of knowledge on the precise physical, chemical and biological processes taking place within a wetland makes prediction of future changes in the functioning of the wetland difficult.

2.4 The relationship between different variables in nutrient cycling in wetlands.

Wetlands whether natural or artificial are able to remove contaminants in the water that passes through them by interaction of different variables as shown in Figure 3. As a result of human activities in the catchments, nutrients and other pollutants find their way into wetlands which leads to increased productivity and eutrophication, while the physical-chemical variables within the wetland depend on the climate, hydrology, seasonality as well as human activities. Other intervening variables include water regime, level of exploitation and the area covered by the wetland.

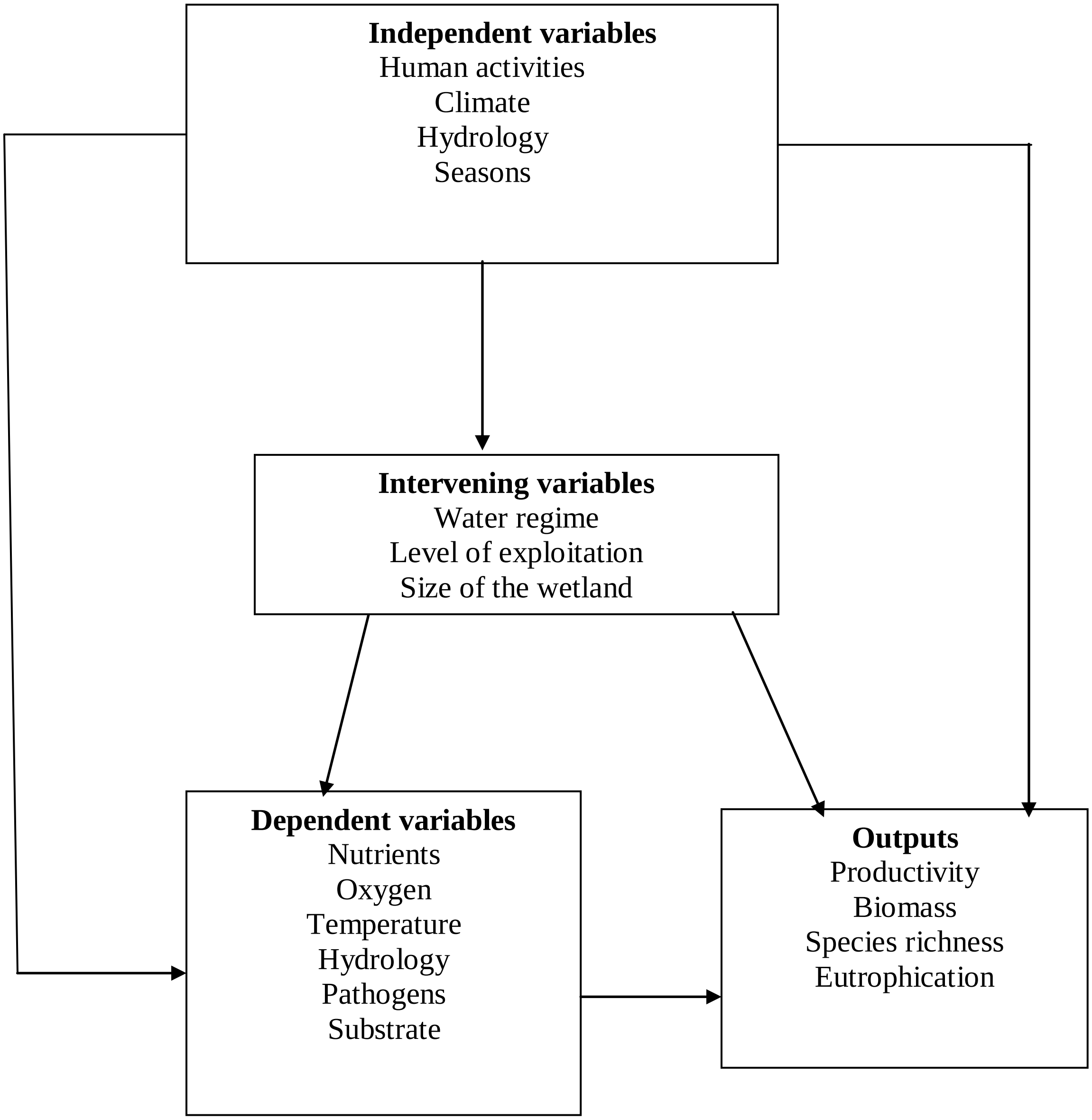


Figure 3: A conceptual framework showing the importance of wetland processes and factors affecting the processes.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

3.1.1 Catchment and location

The Mereronyi catchment is situated in Nakuru district, Rift valley province, Kenya. The River Mereronyi (Figure 4) has a catchment of approximately 120 km^2 straddling between latitude S00^0 11’526’’ and longitude E036^0 13’523’’. It originates from the Aberdare ranges at an altitude of about 1950 metres above sea level m.a.s.l. to about 1840 m.a.s.l. at the mouth where it discharges into Lake Elementaita. The river is 29 km in length from the source to the mouth, while the riverine wetland stretches 3 km long within the lower reach. River Mbaruk is the main tributary. The Mereronyi catchment (Figure 4) comprises of volcanic rocks, with headwater streams having deep, dark brown soils. At the midstream the catchment comprises fairly deep, reddish brown soils; while the lower reaches has shallow brownish soils (Maina Gichaba, Pers. com). The River Mereronyi wetland covered an area of 1.8 km^2 in 1974, and reduced to 0.56 km^2 in 1997 (Figure 4a) adopted from Survey of Kenya map sheet no 119/3, Nakuru During this study the wetland had reduced to approximately 0.45km^2.

3.1.2 Rainfall and water discharge

River Mereronyi catchment has an average mean annual rainfall of 1100mm with a trimodal rainfall regime, with peaks in May, August and November. The short rains occurs between April to May and October to November. Long rains occurs between July and September, while dry periods normally occurs between December and March. However, this pattern could be drastically altered by weather phenomena. For instance, the wet season (*El Ñino)* occurred between 1997 and 1998, which was followed by a long dry period *(La Ñina*) between March 1999 and March 2000 thus altering the usual climatic pattern. In the upper reaches of the River Mereronyi, the system is perennial with permanent discharge though reduces during the dry season. However, drying up of the river in the lower reaches has been observed during prolonged dry seasons.

3.1.3 Human activities

The major human activity taking place in the catchment is agriculture, which involves cultivation of land and livestock keeping. The wetland has been destroyed and replaced with cultivation of crops like maize, bean, bananas, yams and wheat. Other human activities in small scale in the area includes ornamental flower crafts made from the umbel papyrus and trading on household food stuff.

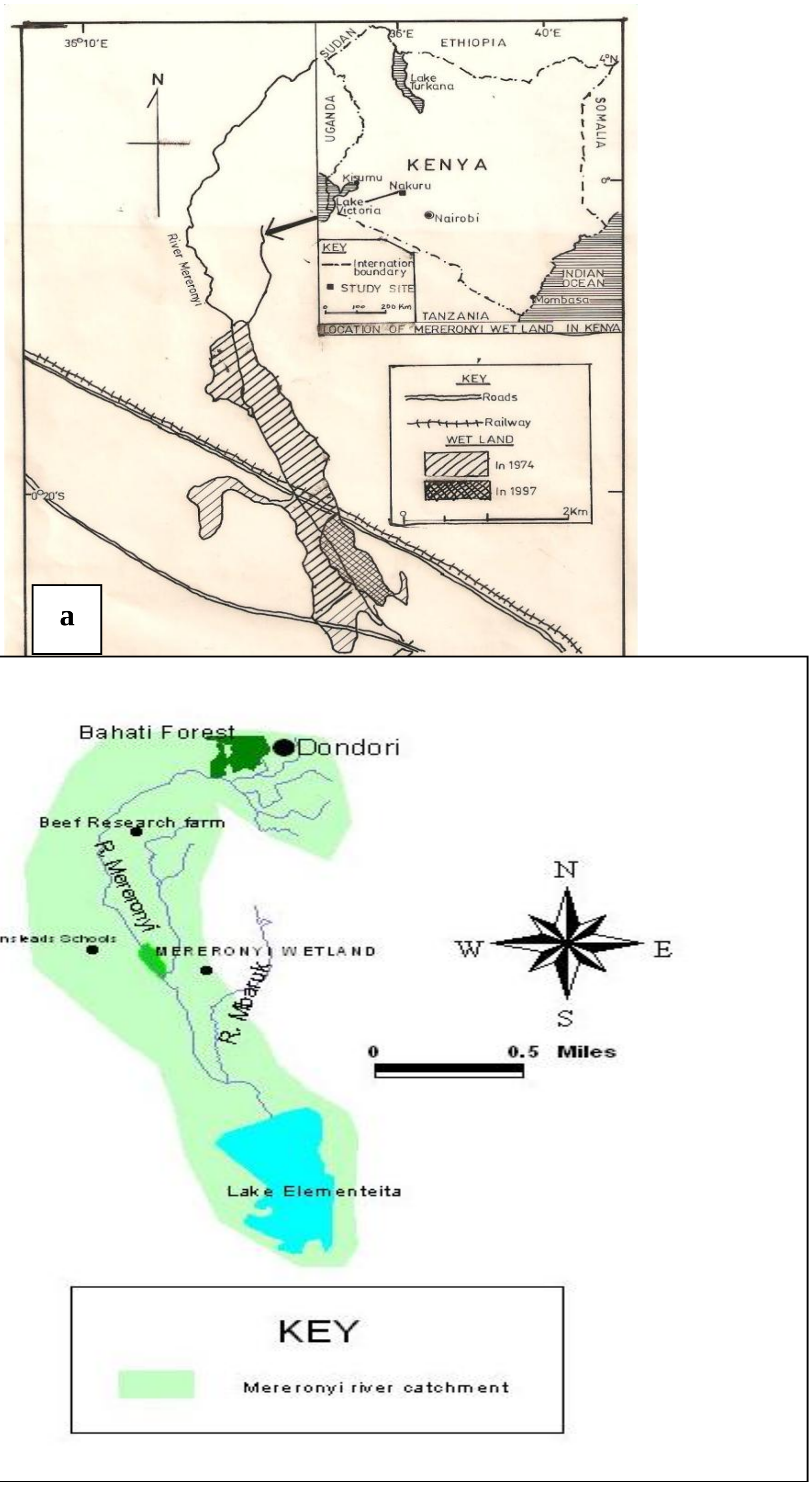


Figure 4: A Map showing the location of Mereronyi river and the wetland in L. Elementaita watershed from Dondori**.**

3.2 Sampling sites

Five sites were chosen along the river Mereronyi wetland as shown in figure 5.

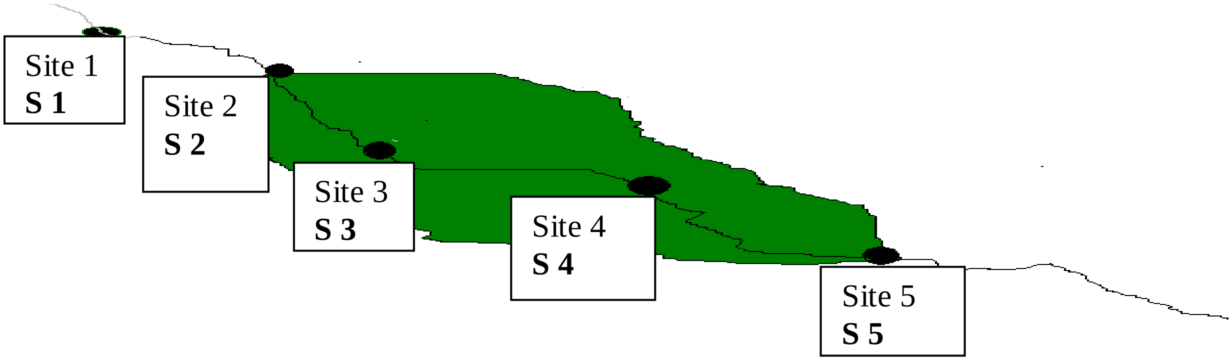


Figure 5: S1 –S5 represent sampling sites during the study period

Site 1(S1) was situated on the upstream of River Mereronyi wetland 200m from the wetland inlet. There was no wetland influence on this site; no riparian vegetation although some grass and some exotic trees were growing along the river banks. Human activities such as cattle watering and washing of clothes were observed in this site. Other human influences are attributed to intensive (large scale livestock and crop production) agricultural activities by Agricultural Development Cooperation (ADC) farm Plate 4, of which the river flows through before it gets into the wetland.

Site 2 (S2) was located in the flood plain section, where the river enters into the wetland before the flow is dispersed. The number and species of aquatic plants abundant as shown in Plate 5. At this site the river divides into two tributaries and eventually spreads out in the wetland. Cattle watering was one of the human activities observed at this site.

In site 3 (S3), was characterized by human activities such as cattle grazing and harvesting of papyrus (plate 6) by the local community. A path used by cattle while getting into the wetland to graze was also observed. There was 20% vegetation cover of papyrus on the left river bank and none on the right river bank except grass.

Site 4 (S4) was characterized by dense papyrus vegetation 90% cover on the left river bank and 60% cover on the right river bank and other aquatic plants as shown in Plate 7. There **were** minimal human activities in this site except for occasional cattle grazing and papyrus harvesting

Plate 4: Agricultural activities along the river Mereronyi wetland at site 1 (ADC farm)

Plate 5: Site 2 where the river enters into the wetland and spreads forming two tributaries.

Site 5 (S5) lies between latitude (S00^{0}20’13’’and E036^{0}11’19’’) with an elevation 1894 m.a.s.l. This was the outlet of water from the wetland. The site was characterized by dense papyrus vegetation with minimal human activities for example fetching water for domestic use.

Plate 6: One of the disturbed site inside river Mereronyi wetland.

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Plate 7: One of wetland sites (S4) with minimal human disturbance.

3.3 Sampling

3.3.1 Water sample collection

Water samples were colleted in clean acid-washed 500ml plastic containers. Before sample collection, bottles were rinsed at least 3 times with the water samples from respective sampling. In each sampling site samples were collected in triplicate before noon. The samples were transported in a cool box to the Aquatic Science laboratory at Egerton University for analysis**.**

Samples for dissolved nutrients were filtered immediately using Whatman Glass Fibre Filters (0.45µm, GF/C). Incase of incomplete analysis samples were kept in the refrigerator until the following day.

During each sampling session the following parameters were determined *in situ*; electrical conductivity, pH, temperature and oxygen concentration, which were measured using respective WTW probes. Discharge was determined using Velocity/Area method as illustrated in Figure 6. Thereafter discharge calculations were done using the formulae; $Q = \sum y_i A_i$ (Wetzel ,2001).

Where y_i is the mean current velocity (m/s) measured at 60% depth and A_i the river cross section area (m^2).

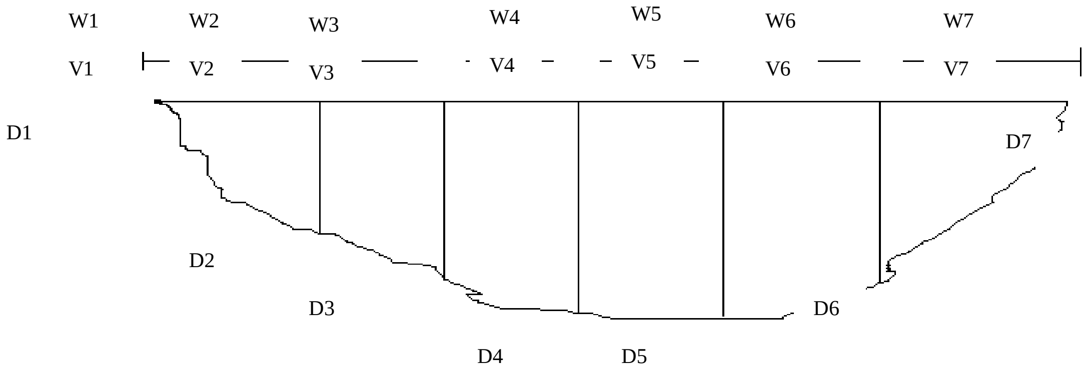

Figure 6: An illustration of a cross section of a river/stream for discharge measurement

W= Width, V= Volume, D= Depth

3.3.2 Sediment sample collection

Sediment samples were collected weekly for two months. The samples were collected in duplicate from the five sites along the wetland. During each sampling session, samples were collected using a corer sampler, which enabled extraction of undisturbed and intact sediment cores. The sediments were immediately stored in polythene bags and kept in a cool box prior transportation to the laboratory for processing and analysis as described in section 3.4.3 and 3.4.4.

3.3.3 Plant sample collection

The standing wetland biomass was measured using harvest method, where all the vegetation in 1×1m random quadrats were cleared by cutting above the rhizome in papyrus as described by Denny (1985). Re-growth and shoot productivity were monitored by harvesting 0.25 × 0.25m plots after every two weeks for a period of 8 weeks. The harvested shoots were then separated into different plant parts (culms and umbels).

3.4 Sample analysis

Chemical analyses of water samples were done according to the standard methods described in APHA (1996). Samples for soluble nutrients; SRP, NO_3-N and NH_4-N were filtered immediately through GF/C (0.45μm) filters. Samples stored in the refrigerator were allowed to warm to room temperature before analysis. The absorbance in each calorimetric analysis was used to estimate concentrations by standard calibration curve.

3.4.1 Phosphorus in water samples

Soluble Reactive Phosphorus was analyzed using ascorbic acid method. Ammonium molybdate solution, sulphuric acid, ascorbic acid and potassium antimonyltartarate solution were mixed in a ratio of 2:5:2:1. 2.5ml of the reagent mixture was added to 25ml filtered sample and the absorbance was read at 885nm wavelength using a spectrophotometer (Pharmacia Biotech.) after 15 minutes.

Total Phosphorus (TP) was determined by reducing the forms of phosphorus present in the water into Soluble Reactive Phosphorus (SRP) using persulphate digestion. This was done by adding 1ml potassium persulphate solution to 25ml sample and autoclaving for 90 minutes at about 120 ^oC and 1.2atm. After digestion, the phosphorus was analyzed using the ascorbic acid method.

3.4.2 Nitrogen in water samples

Nitrate nitrogen (NO_3-N) was determined using the sodium salycilate method, where 1ml of sodium salycilate was added to 20ml sample and left to evaporate overnight at 80^0C*. The residue was digested using 1ml H_2SO_4, after which 40ml of distilled water was added. 7ml sodium hydroxide-tartarate solution was added and the absorbance determined at a wavelength of 420 nm. Ammonium -nitrogen was analyzed by adding 2.5ml sodium salicylate solution and 2.5ml hypochloride solutions and incubated in the dark for 2hours. The absorbance was determined at a wavelength of 665nm.

Total nitrogen (TN) in water samples was determined by Kjeldahl digestion method where free ammonia was liberated through steam distillation in the presence of excess alkali (NaOH). The distillate was collected in a receiver (50ml conical flask) containing excess boric acid then titrated against 0.07144 N H_2SO_4. The nutrient concentrations obtained **from the analysis above** were used to estimate nutrient loading in river Mereronyi wetland using the OECD (1982) model

Nutrient loss/yield (kg)/day = Discharge (L/S) × Concentration (mg/L) × 0.0864(constant)

Where 0.0864 is a conversion factor from mgs^{-1} to kgd^{-1} (Kitaka, 2000).

3.4.3 Phosphorus in the sediment samples

In the laboratory, sediment samples were dried in an oven at 40^oC and ground using a pestle and a mortar. The sediment samples were digested based on Kjeldahl oxidation and then incubated at 360^oC for 2 hours. Hydrogen peroxide was added as an additional oxidizing agent, using selenium as a catalyst, while lithium sulphate was added to raise the boiling point of the mixture. The digest was analysed for phosphorus and nitrogen in the sediment.

Total phosphorus was determined spectophotometrically according Ryan *et al.*, (2001) modified method. In this modified method, a single solution reagent containing ammonium molybdate, ascorbic acid and antimony was used for color development in the sediment extract. The concentrations were estimated using a standard calibration curve.

3.4.4 Nitrogen in the sediment samples

Total nitrogen was analyzed using Kjeldahl method. This method requires complete oxidation of organic matter, accomplished through wet-acid oxidation based on Kjeldahl oxidation. Lithium sulphate was added to raise the boiling point and to convert organic nitrogen into ammonium –nitrogen by steam distillation. The distillate was collected in concentrated boric acid and then titrated against dilute sulphuric acid of pH 5.0 and concentrations computed using the formula given below (Ryan *et al.*, 2001).

$$N\ (mgg^{-1}) = \frac{\text{(Blank titrant-Sample titrant)} \times \text{Acid factor (1.4007)}}{\text{Sample weight}}$$

Where N= Total nitrogen concentration in sediment

3.4.5 Total Suspended Solids

Total Suspended Solids (TSS) was estimated gravimetrically. A known volume of water samples was filtered using pre-weighed Glass Fiber Filters 0.45µm pore size (Whatman GF/C filters) , and then dried at 95^oC to a constant weight. The total suspended solids were estimated according to Wetzel (1991) formulae;

$TSS\ (mgl^{-1}) = (Wc - Wf) \times 10^6 / V^{-1}$

Where TSS= Total Suspended Solids

W_f = Weight of pre-combusted filters in grams

W_C = Constant weight of filter + residue in grams

V= Volume of water sample used in ml

3.4.6 Determination of plant biomass and nutrient analysis

Biomass was estimated using harvest method (Kansiime and Nalubega, 1999). The harvested plant materials were oven dried at 105^oC for dry mass determination. The biomass was expressed as dry weight per metre square. Dry plant samples for nutrient determination were ground to a size which could pass through a 10mm mesh size using a stainless steel grinder. The ground plant samples were digested based on Kjeldahl oxidation and incubated at 360^oC for 2 hours. The analysis of the digest was carried out using the Kjeldahl method.

3.4.7 Estimation of total coliforms (TC) and faecal coliforms *(E. coli).*

The Heterotrophic Plate Count (HPC) technique was used to detect the total coliforms. Ten factorial dilution series of each sample were made in a saline diluent containing bacteriological peptone ($1gl^{-1}$) and sodium chloride ($8.5gl^{-1}$). Yeast extract agar was used as the basic nutrient agar medium. 1ml sample was put in the plate and 15ml of the medium poured directly to the plate and swirled on the table. After cooling, the sample was incubated at 22^0C for 72 hours. All visible colonies were counted using a stereo microscope (magnification ×10) and total count expressed as No/100ml. The Most Probable Number (MPN) method was used in the detection of feacal coliforms as *E. coli* (APHA, 1996) and counts expressed in MPN/100ml.

3.5 Data analysis

Statistical analysis was carried out using the SPSS statistical software, version 12. All the tests were carried out at 95% significance level. Comparison of variables was performed using analysis of variance (ANOVA), which was followed by testing the difference among means using Tukey’s Honesty Significant Different test (HSD test). Simple linear regression analysis was used to determine the relationships between different variables in water, plant and sediment samples. Student’s t-test was used to determine significant differences between selected physical-chemical and biological variables along the wetland.

CHAPTER FOUR

RESULT

4.1 Spatial variation of physical-chemical variables along the river Mereronyi wetland.

4.1.1 Temperature, Electrical Conductivity, Dissolved Oxygen and pH

The mean values and ranges for temperature, conductivity, dissolved oxygen and pH are presented in Table1. Water temperature in river Mereronyi wetland ranged between 19.3 ± 0.6 - 21.7± 0.3 and range differed significantly between the open river channel (S1) and emergent macrophyte zone (S5) ($t = 2.05$, d.f = 54, $p < 0.05$). The lowest and highest water temperatures of 14.4 ^{o}C and 25.3 ^{o}C were recorded in S5. There was a gradual decrease in the concentration of dissolved oxygen along the river Mereronyi wetland. The water pH did not differ significantly among the sites ($F = 7.56$, d.f = 83, $p > 0.05$). The highest pH range of (3.5-8.8) was recorded in S4 while the lowest pH range of 5.00-7.48 was recorded in S2 (Table 1). There was a significant difference in conductivity among the sites ($F = 3.46$, d.f = 126, $P < 0.05$). A significant difference in conductivity was observed between the wetland inlet and the wetland outlet ($t = 3.876$, d.f = 54, $p < 0.05$).

Table 1: Mean values and ranges of physical-chemical variables at different sites in river Mereronyi wetland. Data presented as mean ± SE (the values in parenthesis are the ranges), (n=160.)

SITE	TEMP (^{o}C)	EC(µS/cm)	DO(mgL^{-1})	pH
S1	21.7 ± 0.3	197 ± 23	6.55 ± 0.13	
	(19.0 - 24.6)	(93 - 483)	(5.2.-10.00)	(5.05 -7.97)
S2	20.8 ± 0.4	195.4 ± 13.1	5.80 ± 0.34	
	(18.0 - 24.7)	(130.0 - 350.0)	(3.10 – 9.60)	(5.00 -7.48)
S3	20.6 ± 0.4	167.2 ± 3.7	4.82 ± 0.35	
	(17.0 - 25.5)	(131.0 -202.0)	(2.60 – 8.50)	(3.81- 8.10)
S4	20.7 ± 0.4	207.0 ± 24.1	4.57 ± 0.29	
	(17.0 -25.2)	(94.0 - 480.0)	(2.60 -7.80)	(3.50- 8.80)
S5	19.3 ± 0.6	127.6 ± 7.8	3.65 ± 0.19	
	(14.4 -25.3)	(63.0 -180.0)	(2.00 -5.60)	(3.56 -7.63)

4.1.2 Total Suspended Solids (TSS)

The mean TSS was highest in the disturbed site within the wetland (S3) (1781 ± 332.70 mgL^{-1}) and lowest (283.6 ± 188.03 mgL^{-1}) in S4 with minimal disturbance (Figure 7).

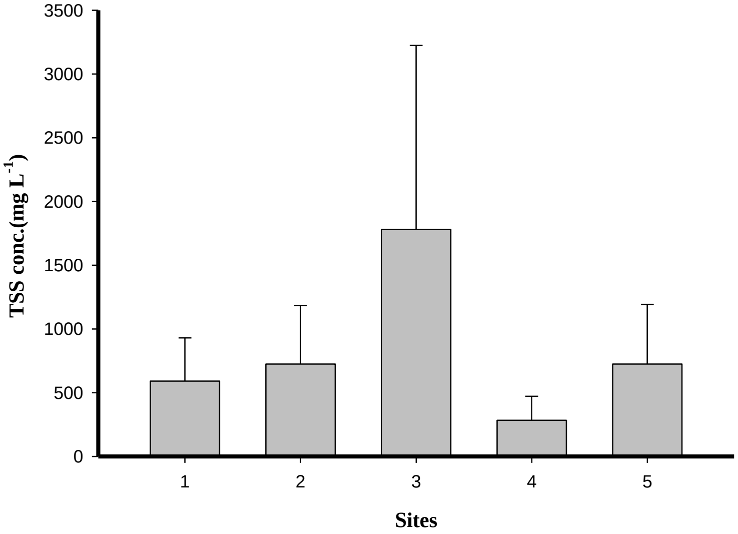

Figure 7: Variation of Total Suspended Solids along the river Mereronyi wetland. Vertical lines show the SE, n=105

4.1.3 Nutrients in water

(a) Soluble Reactive Phosphorus (SRP) and Total Phosphorus (TP)

Mean TP varied significantly among the sites (ANOVA, F = 7.53, d.f =119, $p < 0.05$). Post hoc analysis indicated a significant difference between S4 and S5 (Tukeys', HSD test, $p < 0.05$). However, SRP showed no significant variation among the sites (F =1.71, d.f =115, $p > 0.05$) as presented in Figure 8. Though not significant, there was a decrease in SRP from S4 to S5. The mean ratio of SRP to TP was 1: 1.6 in the river Mereronyi wetland.

(b) Ammonium-nitrogen and nitrate-nitrogen

The mean concentration of ammonium was highest (0.5 ± 0.11 mgL^{-1}) at S1 and lowest at S2 (0.3 ± 0.04 mgL^{-1}) (Figure 9). But, there was no significant variation among the sites (ANOVA, F = 2.12, d.f = 106, $p > 0.05$). Mean nitrate concentration ranged between 0.30 ± 0.05 mgL^{-1} and 0.50 ± 0.04 mgL$^{-1.}$ There was no significant difference in the mean concentration of nitrate-nitrogen among the sites (F = 2.13, d.f =110, $p > 0.05$).

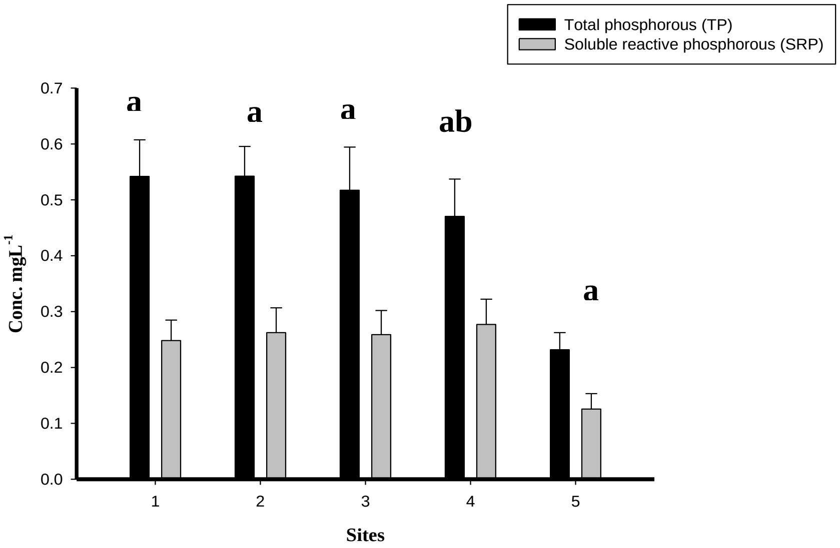

Figure 8: Total Phosphorus and Soluble Reactive Phosphorus concentrations along the sampling sites in river Mereronyi wetland. Vertical lines show the SE, (n=120 for TP and n=116 for SRP). N.B Means with the same superscript (a, b) are not significantly different, while means with superscripts (ab) indicates a significant difference between a and b at P = 0.05 level (Tukeys test)

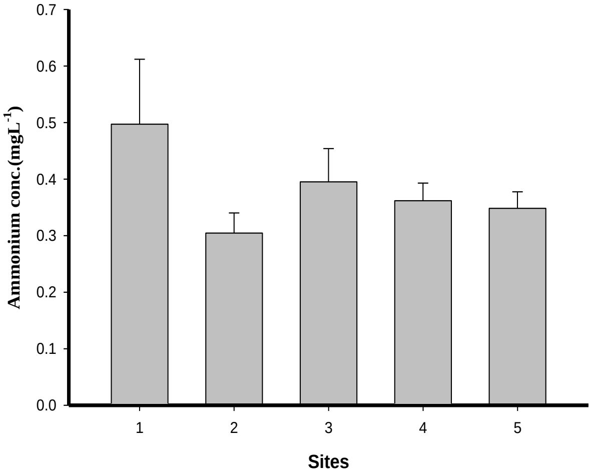

Figure 9: Variation of ammonium-nitrogen in selected sites along the river Mereronyi wetland vertical lines show the SE, (n=107)

4.2 Temporal variation of physical-chemical variables along the river Mereronyi wetland.

4.2.1 Temperature, conductivity, pH and dissolved oxygen

Temperature differed significantly during the sampling period (F = 3.94, d.f = 6, $p < 0.05$). The lowest mean temperature of 15.7 ± 3.89 ^{o}C was recorded on 13/6/08 (Table 2), while the highest (22.6 ± 0.94 ^{o}C) was recorded on 9/5/08. From Table 2, it is observed that there was an elevated electrical conductivity from mid May to early June. However, electrical

conductivity did not differ significantly among the sampling dates (F = 0.571, d.f = 6, p > 0.05). The lowest mean dissolved oxygen value was recorded on 23/5/08, while the highest was recorded on 13/6/08. There was a significant difference in dissolved oxygen concentration among different sampling dates (F = 42.22, d.f, 20, P > 0.05). Post hoc analysis (Tukeys, HSD test, p < 0.05), indicated significant difference between different sites as shown in Table 2 below. Highest pH (7.19 ± 0.23) was recorded on 16/5/08 while the lowest (5.50 ± 1.37) was recorded on 13/6/08. pH did not differ significantly among the sampling dates (F = 2.51, d.f = 6, p > 0.05).

Table 2: Mean values and ranges of physical-chemical variables at different sampling dates (pooled data over the sampling period) in river Mereronyi wetland. Data presented as mean ± SE, (n =160)

Sampling dates	Temperature (°C)	Conductivity (µS/cm)	Dissolved Oxygen (mgL^{-1})
9/5/08	22.6 ± 0.9	175 ± 29	4.97 ± 0.25 (a)
16/5/08	20.9 ± 0.4	150 ± 28	4.67 ± 0.55 (a)
23/5/08	19.0± 1.3	220 ± 67	3.59 ± 0.53 (a)
30/5/08	19.5 ± 0.6	217 ± 34	4.15 ± 0.69 (bc)
6/6/08	21.9 ± 0.3	194 ± 17	4.44 ± 0.62 (c)
13/6/08	15.7 ±3.9	131 ± 29	5.09± 1.29 (d)
20/6/08	22.0 ± 0.3	194 ± 17	4.44± 0.62 (e)

N.B. Means with the same superscript (a, b, c, d, e) are not significantly different at P = 0.05 level while (bc) indicates significant difference between a, d and e (Tukeys test).

4.2.2 Nutrient concentration in water; A comparison between wetland inlet (S1) and wetland outlet (S5) on different sampling dates.

(a) Total phosphorus (TP), Ammonium-nitrogen and Nitrate- nitrogen

TP was high in S1 and low in S5 on the different sampling dates as shown in Figure 10 except on 30/5/08. There was hardly any difference in concentration between the two sites on 30/5/08; however, TP differed markedly between the two sites on 23/5/08. A significant difference was observed between the concentrations of TP at the wetland inlet and wetland outlet on different sampling dates (t = 6.10, P< 0.05). There was no significant difference in

nitrate concentration observed between S1 and S5 (t = 1.39, d.f = 12, $p > 0.05$) as shown in Figure 11. Drastic decline of nitrate concentration in S5 were observed on 30/5/08 and 6/6/08 giving the highest concentration difference between S1 and S5. However, 16/5/08 and 23/5/08 recorded the lowest nitrate reduction from S1 to S5 respectively.

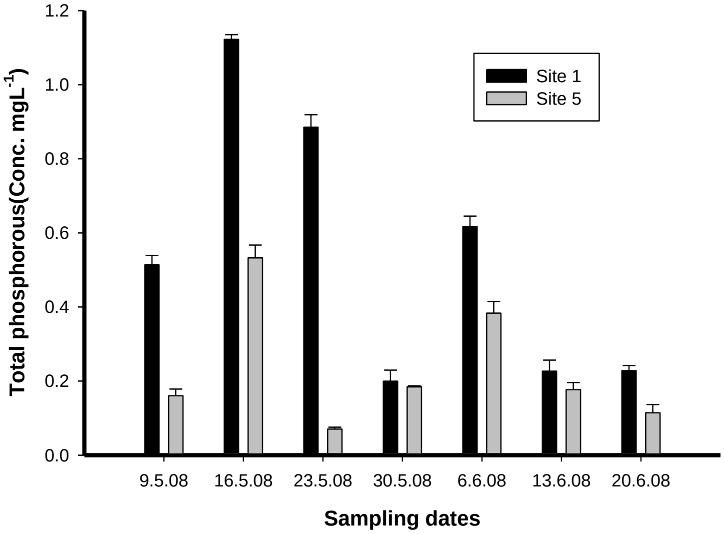

Figure 10: Variation of total phosphorus concentrations at different sampling dates at S1 and S5. Vertical bars represent SE, (n = 15).

There was significant variation of ammonium-nitrogen between the sites (F = 20.66, d.f 16, $p < 0.05$) (Figure 12) with a sharp increase in pH and ammonium in S1 on 23/5/08. This was followed by the lowest mean concentration of ammonium between S5 coinciding with a markedly decline in pH at S5 on 30/5/08. However, there was no significant correlation between pH and ammonium (Pearsons correlation, r = 0.073) obtained during this study.

4.3 Variations in concentration of total phosphorus and total nitrogen in the sediment at the river Mereronyi wetland.

In aquatic ecosystems, there is usually exchange of nutrients between water column and underlying sediments. There was no significant variation among the sites in the concentrations of TP in the sediment (F =1.357, d.f = 4, $p > 0.05$). There was a sharp increase in TP concentration from S1 to S2, which was followed by progressive decline from S2 to S5 (Figure 13a). A progressive increase in TN concentration was observed from S1 to S3 followed by a progressive decline from S3 to S5 (Figure 13 b). TN concentration was highest in the disturbed site (S3).

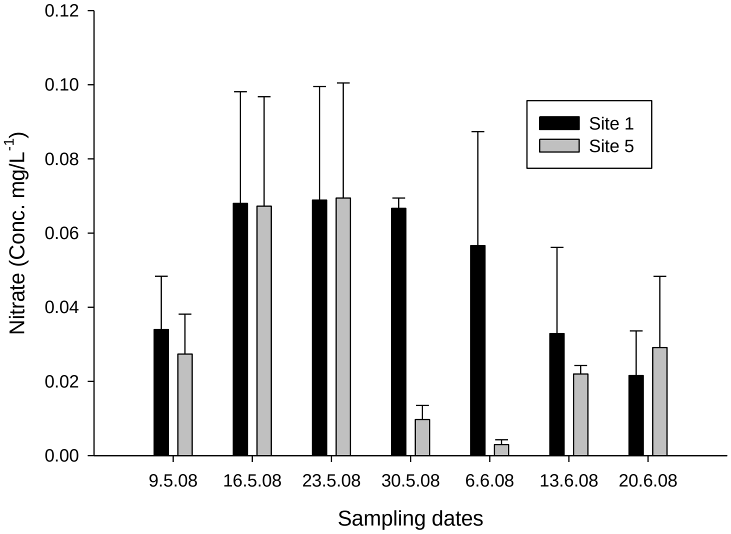

Figure 11: Temporal variation of nitrate nitrogen at S1 and S5 respectively for different sampling sessions, (n=13).

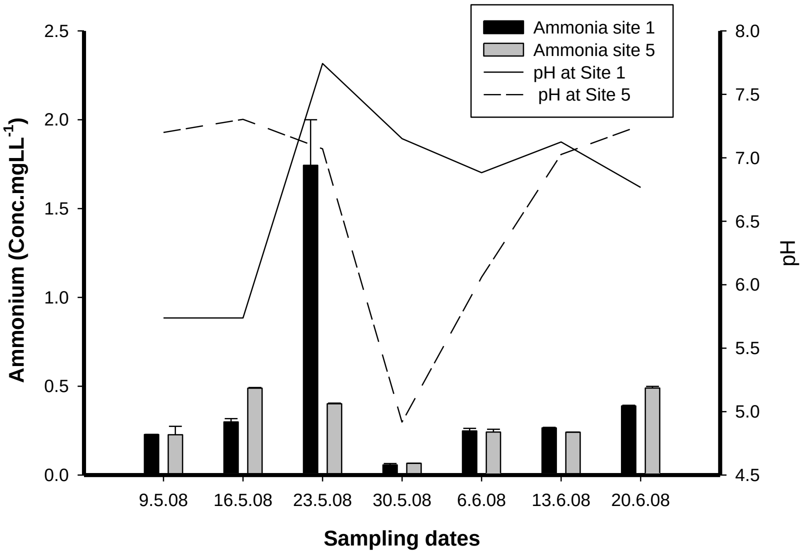

Figure 12: Temporal variation of ammonium and pH at site 1 (wetland inlet) and site 5 (wetland outlet) during different sampling sessions.

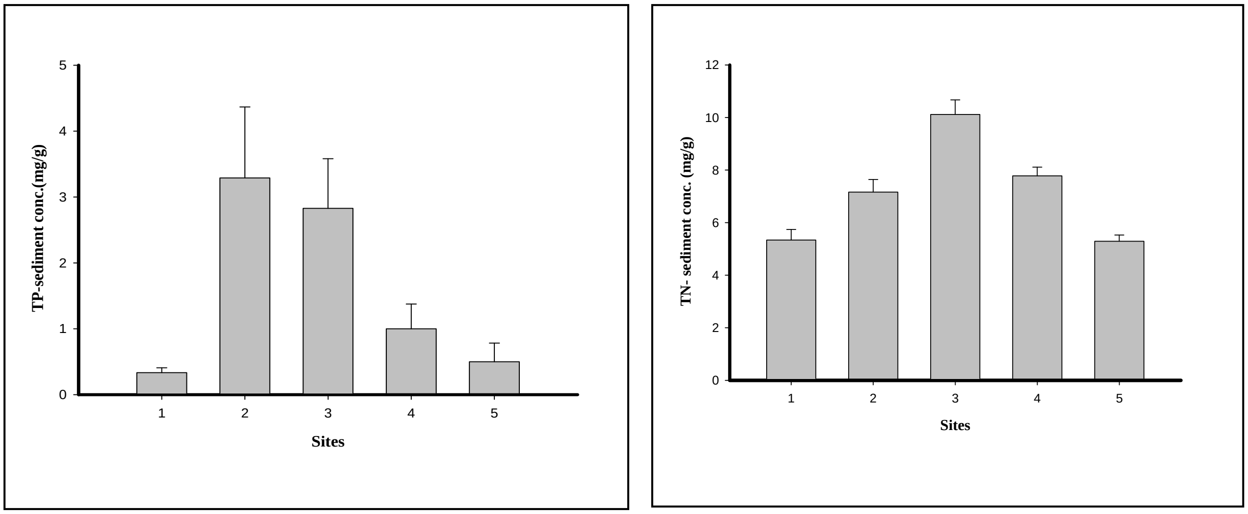

Figure 13: Variation of TP (a) and TN (b) concentration in the sediment along river Mereronyi wetland. n=5

4.4 Productivity of *Cyperus papyrus* in river Mereronyi wetland.

There was a steady increase in the net primary productivity over time (Figure 14). The lowest Growth rate of 0.005dmg^{-1}m^{2}d^{-1} was recorded between 14th and 28th day. However, rapid growth rate of 1.45 dmg^{-1}m^{2}d^{-1} was recorded after 28th to the 42nd day. The growth rate reduced to (0.29 dmg^{-1}m^{2}d^{-1}) after the 42nd to the 56th day. The total above ground biomass was 21.84 tonnes /ha.

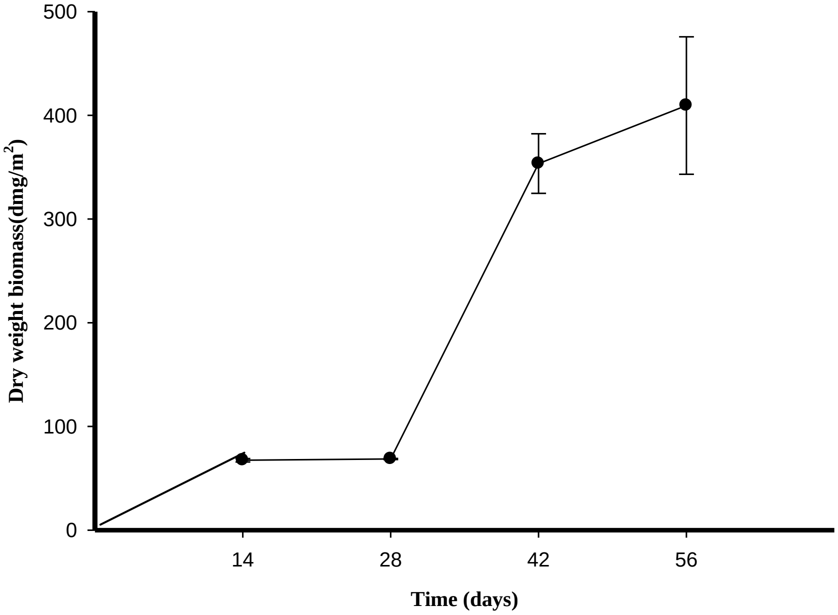

Figure 14: Aerial biomass productivity against time of papyrus in River Mereronyi wetland (n = 24).

4.5 Relationship between nutrients in water, sediments and plants.

Simple linear regression analysis showed significant negative correlation between TP in plants and TP in the sediments as illustrated in matrix. There was no significant correlation between TN in water, sediment and plants. However, there was significant positive correlation between TN in water and TN in plants as shown in Table 3b. TP showed a negative correlation between sediment and water as illustrated in Table 3a.**

Table 3: Correlation matrix and test matrix of TP and TN in water, sediment and plants.

a)

	TP-water	TP-Plants	TP-sediment
TP-water	**1.00**	**0.08**	**-0.03**
TP-plants	**0.08**	**1.00**	**-0.95(**)**
TP-sediment	**-0.03**	**-0.95(**)**	**1.00**

b)

	TN – plants	**TN-sediment**	**TN-water**
TN – plants	**1.00**	**0.09**	**0.91(*)**
TN – sediments	**0.09**	**1.00**	**0.35**
TN – water	**0.91(*)**	**0.35**	**1.00**

*** Correlation is significant at the 0.05 level.**

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

4.6 *E. coli* and total coliforms in wetland waters

Part of wetland flora are the micro-organism commonly used as indicators of water pollution. In this study *E. coli* was used to determine feacal pollution and probability of recent feacal pollution along the study sites. High numbers of *E. coli* were recorded in S1, 3, and 5 with the wetland outlet (S5) having the highest number of *E. coli* (mean of 516 ± 69.97 MPN/100ml). Total coliforms measured as HPC (No/100ml*)* was highest in S3 and lowest in S4 (Figure 15). There was no significant difference in *E. coli* and total coliforms concentrations among different sites within the wetland (F = 2.045, d.f, P > 0.05; F = 0.03, d.f = 20, P > 0.05.

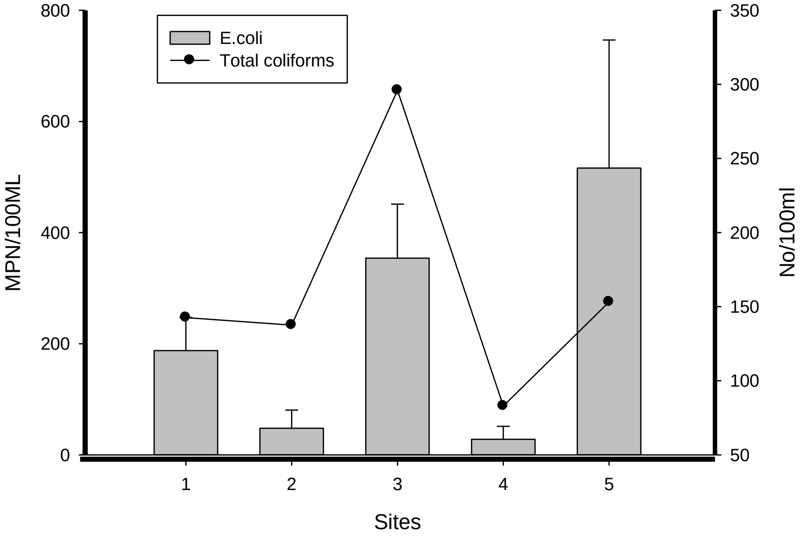

Figure 15: Comparison between the variation of *E. coli* and total coliforms along river Mereronyi wetland.

4.7 Removal efficiencies and nutrient mass balance of river Mereronyi wetland.

Removal efficiencies calculated for nitrogen and phosphorus in the river Mereronyi wetland indicated a high efficiency for phosphorus component; SRP (61.8%), TP (57.4%) and low efficiency for nitrogen component; Nitrate (32.70 %), Ammonium (20 %) and TN (31%). Nitrogen and phosphorus mass balance demonstrated by average nutrient fluxes are shown in Figures 16 and 17 respectively. Phosphorus concentration reduced to almost half in the wetland sediment. Notably is the minimal removal of TP in the water column between the wetland inlet and outlet. The nutrient loading per day in the river Mereronyi wetland was calculated as 355kgd^{-1} of TN and 232.85kgd^{-1} for TP was obtained as presented in Figure 16 and 17 respectively.

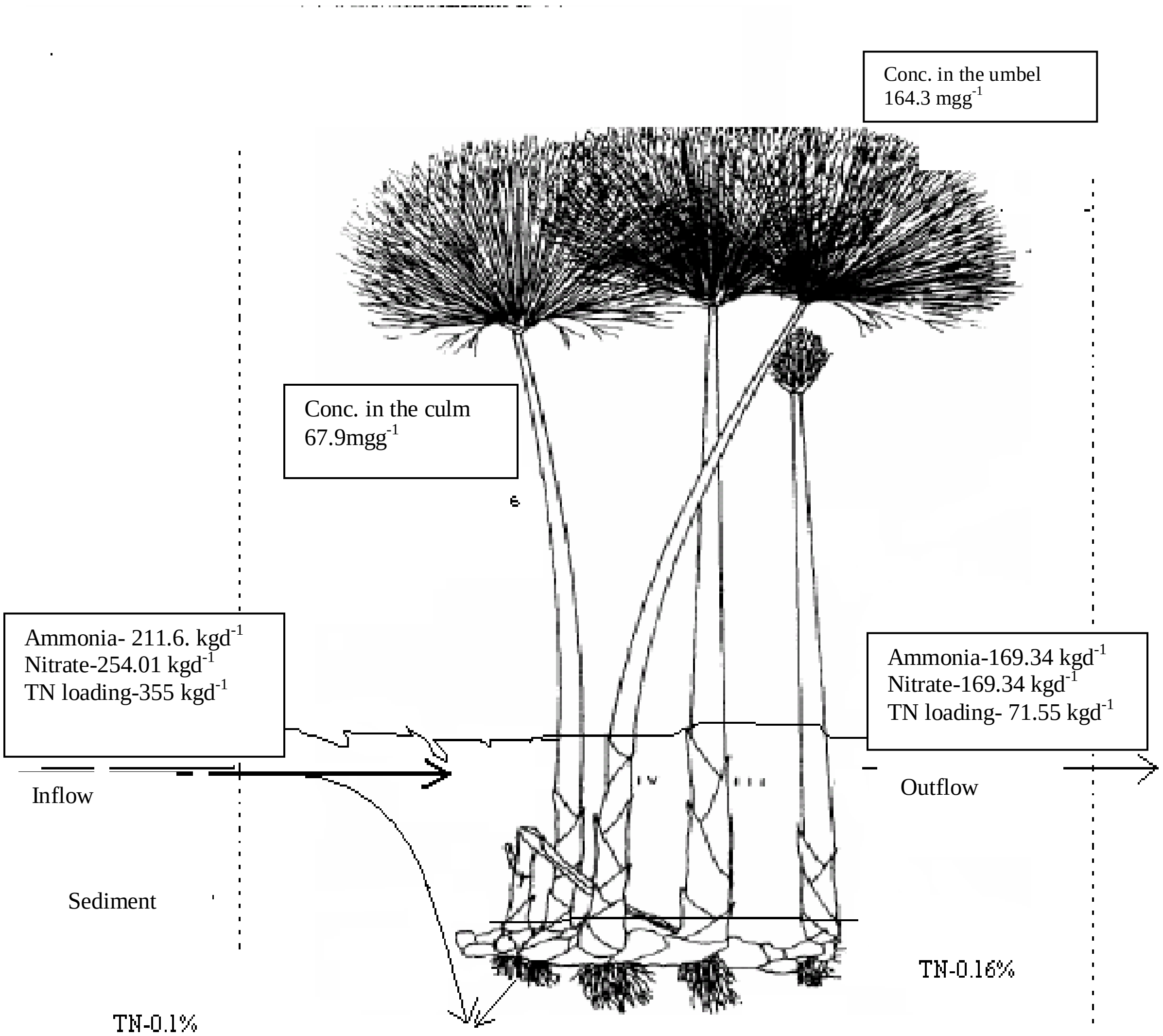

Figure 16: Average nitrogen fluxes for the river Mereronyi wetland (estimated using the approach by Muthuri and Jones, 1997).

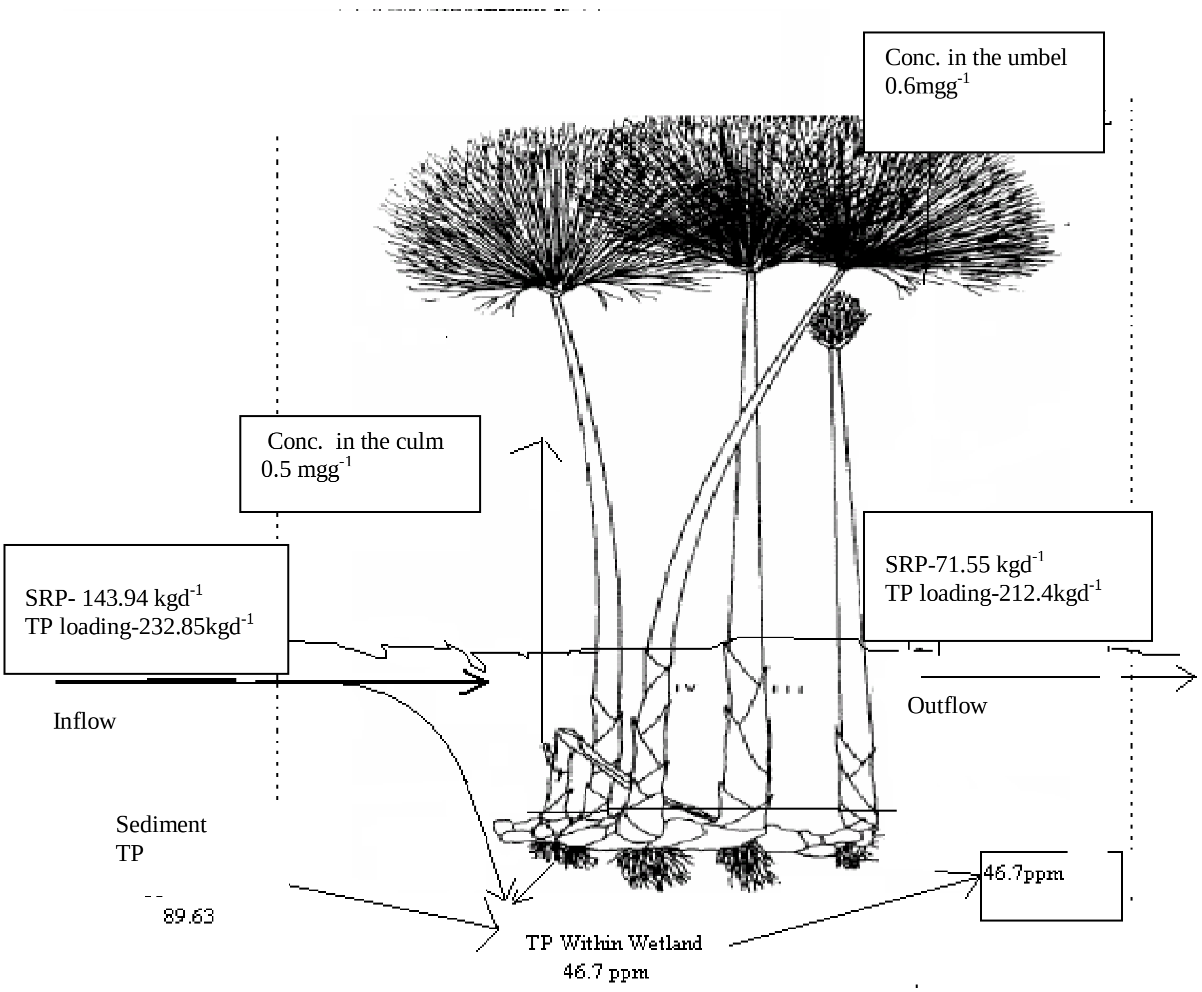

Figure 17: Average phosphorus fluxes for the river Mereronyi wetland. (Estimated using the approach by Muthuri and Jones, 1997).

CHAPTER FIVE

DISCUSSION

5.1 Overview

Several human activities were observed along river Mereronyi catchment. These include farming, cattle grazing, washing of clothes and human waste disposal among others. The water inlet in river Mereronyi wetland was characterized by high concentrations of nutrients, although the results revealed significant reduction in nutrient concentrations at the wetland outlet, as a consequence to wetland influence. Papyrus wetlands have been reported to reduce nutrients through uptake and subsequent storage in plant tissues (Gaudet, 1977; Kansiime and Nalubega, 1999). The enormous wetlands at the terrestrial/ aquatic ecotones of Eastern and Central Africa form buffers that regulate water quality in the receiving waters. There is a close relationship between human population density and nutrient enrichment in aquatic ecosystems (Lung'ayia *et al*, 2001). An increase in development activities has resulted in to gradual changes in land use and a general degradation of the environment. The dominant vegetation in Mereronyi riverine wetland consisted of *Cyperus papyrus* while others included *Cyperus spp*, *Sphaeranthus suaveolens, Senna didymobotrya, Polygonum pulchrum, Ipomoea spp, Pennisetum clandestinum (*kikuyu grass*)* and *Eleusine jaegeri (*Manyatta grass*).*

5.2 Influence of wetlands on physical and chemical parameters of water

5.2.1 Temperature, Dissolved Oxygen, pH and Electrical Conductivity

High temperatures experienced in S1 which had an open canopy along the river channel, could be attributed to direct penetration by sunlight into the river. In S2, S3, S4 and S5, temperatures were relatively lower due to the shading effect of the papyrus canopy. Similar results were reported by Bett (2006) from a study in a constructed wetland in Kenya. The highest temperature was recorded on a sunny day while the lowest temperature was recorded on a cloudy day. The significant variation in temperatures could be explained by observed different weather conditions during the sampling days.

The observed low levels of dissolved oxygen are within the range reported for other papyrus wetlands in Africa (Chapman *et al.*, 2000). This could be attributed to high oxygen demand exerted by decomposing organic matter in the wetland. The oxygen concentration in water is known to be influenced by temperature (Wetzel, 2001). Organic matter

decomposition and respiration by organisms in the wetland could also explain the decrease in oxygen concentration in the river Mereronyi wetland through conversion of nitrates to ammonium.

The pH values in river Mereronyi (3.5-8.8) were within the range reported for other papyrus wetlands in East Africa (3.0-9.5) by Gaudet, (1977) and other natural wetlands. Similar pH values were reported by Verhoeven, (1986); Kadlec and Knight, (1996); Azza *et al*, (2000) for ombrotrophic wetlands. The low pH values (3.5) in river Mereronyi wetland could be as a result of exchange of metal ions for H^+ by the plants root mat (Kadlec and Knight, 1996), this condition could also be attributed to increase in CO_2 concentration and humic acids. The formation of humic and fluvic acids during organic matter mineralization has also been cited to reduce pH by Kansiime and Nalubega, (1999).

In this study, electrical conductivity ranged between (63-207µS/cm), which lies within the range (88- 240 µS/cm) values reported by Bugenyi, (1993) for tropical wetlands. High conductivity observed in different sites of the wetland could be attributed to human activities within the wetland. These include farming, washing of clothes, cattle watering and leaching of nutrients and other ions from the decaying wetland plants which introduce ions into the water column. However, reduction in conductivity in different sites could be attributed to removal of ions from the water either through uptake of ions by plants, through the process of sedimentation or adsorption process by wetland sediments.

5.2.2 Total Suspended Solids, Total Phosphorus and Soluble Reactive Phosphorus

The highest TSS value recorded in S3 which is a disturbed site within the wetland could have resulted from re-suspension of fine particles into the water column. The reduction in TSS between S4 and S5 can be attributed to increase in sedimentation rate accelerated by the roots and culm of the wetland vegetation and the presence of adsorption surfaces including debris in the wetland.

Phosphorus enrichment of sediments can act as an internal source of nutrients to the water column (Bostic and White, 2007). In river Mereronyi wetland, there was significant decrease in TP concentrations in the water column between S4 and S5, this could be attributed to the anaerobic conditions at these sites. The anaerobic condition favours the conversion of TP in the form of bound phosphorus to soluble forms that can easily be taken up by aquatic plants. The anaerobic condition in the river Mereronyi wetland led to the

release of bound phosphorus in the sediment as SRP, a similar observation was made on 23/5/05 where the removal rates of TP was high between S1 and S5. The negative relationship between TP in plants and TP in the sediment could further explain the conversion of TP to a readily available SRP, which is easily taken up by wetland plants. The reduction of TP from the wetland inlet to the wetland outlet on different sampling dates is an indication of the positive influence of the wetland in nutrient removal. From the results, it can be suggested that the wetland significantly removed TP in the water column from the wetland inlet to the wetland outlet. The increase in TP concentration in the sediment from S1 to S2 could be attributed to increase in sedimentation rate due to the reduced water velocity as it gets into the wetland or enhanced sedimentation by roots and culms. The progressive decrease after S2 could be attributed to the anaerobic conditions in wetlands that leads to desorption of soluble reactive phosphorous from the sediment that is taken up by plants.

5.2.3 Ammonium-nitrogen, nitrate-nitrogen and Total- nitrogen

In the upstream of river Mereronyi wetland the level of ammonium was relatively high; this could be attributed to the use of fertilizer (di-ammonium phosphate) by farmers which enters the water column through runoff. The highest concentration of ammonium recorded at the wetland inlet on 23/5/08 could be attributed to heavy rainfall observed the previous day, resulting to input of ions through runoff from the catchment. The decrease in ammonium concentration from S1 to S2 could be explained by the release of oxygen by the rhizosphere of the papyrus which leads to the conversion of ammonium to nitrate, which are in turn taken up by emergent aquatic plants. An increase in ammonium concentration in the disturbed site is likely to be due to the reduction of oxygen concentration hence conversion of nitrate to ammonium through denitrification process. The increase in ammonium concentration could also be related to mineralization of dissolved organic matter released by wetlands as well as the inhibition of the nitrification process by tannin derivatives as reported by Wetzel and Likens (1983) due to low pH values and low concentration of dissolved oxygen in S3. Low concentrations of ammonium at the wetland inlet and wetland outlet on 30/5/08 could be attributed to reduction in pH observed during the study hence conversion of ammonium to nitrate.

Nitrification and denitrification depends on oxygen concentration in any system, for example decrease in dissolved oxygen between S4 and S5 resulted to a decrease in nitrate concentration in the same sites as a result of denitrification process. Low oxygen concentration results to the process of denitrification (Wetzel, 2001), where decrease in nitrate concentration between S1 and S5 was recorded on 30/5/08 and 6/6/08 when the oxygen concentration was low as a result nitrates were converted to ammonia. The progressive increase in TN concentration in the sediment from S1 to S3 was as a result of decomposition of organic matter in the wetland. The highest concentration observed at S3 could be attributed to external sources such animal waste due to disturbance. There was no correlation between the TN in sediment and TN in plants probably due of the presence of external sources of TN especially in the disturbed site.

5.3 Productivity and aerial biomass of papyrus plants in river Mereronyi wetland

Vegetation is a key biotic component in wetland ecosystems. Plants require nutrients for production of new cells during growth. But the standing biomass of papyrus plants are determined by available light, local temperature regimes irrespective of site quality (nutrients status) for any particular climate zone (Thompson *et. al.* 2008). Papyrus exhibits high growth rates and in this study an average growth rate of 0.6dmg^{-1}m^{2}d^{-1} was measured. However higher growth rates of (18dmg^{-1}m^{2}d^{-1}) have been observed for papyrus swamp in L. Naivasha (Muthuri and Jones, 1997). The availability of nutrients like nitrogen and phosphorus and their subsequent reduction in concentration along the wetland implies an increase in bio-uptake resulting to high growth rates and higher biomass production. Vegetation can act as short-term phosphorus storage, which can rapidly release 35 to 75% of the total plant-associated phosphorus during senescence, potentially increasing the water phosphorus concentrations (White *et al.*, 2004; 2006; Corstanje *et al.*, 2006).

The values of aerial biomass reported here are in the range reported in the previous studies undertaken in Eastern Africa as illustrated in Table 4 below.

Table 4. Aerial biomass of papyrus from different studies in Africa.

Country	**Location**	**Biomass (dmgm^{-2})**	**Source of information**
Zaire	**Upemba swamp**	**115 - 1163**	**Thomson *et al.*, 1979**
Uganda	**Akika Island**	**5000**	**Jones and Muthuri**

			1985
Kenya	**Lake Naivasha**	**5307**	**Muthuri *et al*., 1989**
Uganda	**Kampala**	**2219**	**Kyambadde *et al*.,2004**
Rwanda	**Busoro swamp**	**1384**	**Jones and Muthuri 1985**
Kenya	**River Mereronyi wetland**	**2184**	**Present study**

The average biomass for papyrus in river Mereronyi wetland is within the range reported in literature (1384-4955dmgm^{-2}) for East and Central Africa (Denny 1993). The productivity values obtained for river Mereronyi wetland of 7.3 dmgm^{-2} was not within, but close to the range of 7.7- 38 dmgm^{-2} values recorded by van Dam *et al,* (2007) for other natural wetlands in East Africa. Nutrient availability is known to affect productivity of papyrus wetlands and photosynthetic capacity of papyrus, productivity is also limited by nitrogen and phosphorus in the umbel (Jones, 1991).

5.4 Variation of bacteria concentration in wetlands

The high concentrations of coliforms in the disturbed site 3 (S3) indicated that their number depended on the amount of degradable organic matter that dropped from the cutting of papyrus on this site. A similar observation was made by Kirui, (2001) in Ombeyi wetland. *E. coli* depends on the availability of faecal material in the catchment (Kansiime and Nalubega, 1999). In this study it was observed that high numbers of *E. coli* were recorded in the disturbed site and the wetland outlet, where faecal material were observed on the river banks. The reduction in concentrations of bacteria between S1 and S2 which is an open channel could be attributed to natural die off due to the exposure to Ultra Violet (UV) radiation. The decrease between S3 and S4 could be attributed to the influence of wetland as a result of dense papyrus vegetation by sedimentation and or due to biological factors e.g predation.

5.5 Wetland influence on water quality

The variation in water quality along the river Mereronyi wetland indicates that the wetland has an impact on the river water quality. There is a general decrease in the concentrations of nutrients in the water column with respect to the base values in the

wetland inlet, implying retention of nutrients in the wetland. Considering the area of the wetland to be 45ha during this study, with a total above-ground biomass of 942 tonnes, therefore, if the wetland can be reinstated to its original size of 180ha, it is estimated that complete harvest in Mereronyi wetland could remove 3931.2 tonnes of biomass. This implies that the amount of nutrients getting to the river would reduce significantly. Using the average aerial papyrus nutrient content (N, 1.16%; P, 0.16%) the biomass removed would account for 25.3 tonnes of nitrogen and 3.45 tonnes of phosphorus. Since nutrients taken up by plants return to the aquatic environment when plants die, a well managed periodic harvesting of shoots would be one of the management options for nutrients removal from the river Mereronyi wetland.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.0 Conclusions

1. **Physical-chemical variables measured during the study showed spatial and temporal variations along river Mereronyi wetland. Temperature and Electrical conductivity showed a significant spatial variation while dissolved oxygen showed significant variation on different sampling sessions. There was reduction of SRP, NO_3, TN, and NH_4 in water between the wetland inlet and the wetland outlet on different sites along the wetland on different sampling dates, though not significant. However, TP showed a significant variation .There was no significant variation of both TN and TP in the sediment along the River Mereronyi wetland though there was an observed decreasing trend from S3 to S5.**
2. **The significant negative correlation observed between TP in the sediment and TP in plants, indicates that there is nutrient uptake by wetland plants. However there was no significant relationship between TN in sediment and TN in plants due to the allochthonous sources especially in the disturbed site.**
3. **River Mereronyi wetland has a high removal efficiency for SRP (61.8%) as compared to TP (57.4%), NO_3 (32.7%), TN (31%) and a low removal efficiency for ammonium (20%).**
4. **From the study, no significant variation was observed in the total coliform and *E. coli* concentration along the wetland. It can be concluded that high levels of total**

coliforms appeared to occur in a disturbed eco-type as observed in S3 and *E. coli* concentration depended on human activities, where there was observed faecal waste disposal.

6.1 Recommendations

1. **A long term study should be undertaken to understand the spatial- temporal variation of nutrients in water, sediments and plants in the River Mereronyi wetland, this should also include the variation of *E. coli* and total coliforms along the wetland.**
2. **The study recommends that the River Mereronyi wetland be reinstated to its original size (180ha) in 1977; this could be achieved by incorporating NEMA and WRMA in the management of the wetland.**
3. **The community should be encouraged to plant more wetland plants that are of economic importance for example *Cyperus papyrus* to enhance removal efficiencies of nutrients and corliforms in River Mereronyi wetland. However, controllable removal mechanisms such as plant uptake and biomass harvesting should be done but with good management.**

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APPENDICES

Appendix 1: Mean concentration and standard errors of nutrients (mgL^{-1}) and total suspended (mgL^{-1}) solids in different sites along river Mereronyi wetland.

Sites Variable	Site 1	Site 2	Site 3	Site 4	Site 5
Total Phosphorus (water)	0.55	0.54	0.52	0.47	0.23
± SE	0.07	0.05	0.08	0.07	0.03
Total Phosphorus (sediment)	40.60	89.10	60.90	50.60	46.74
± SE	6.31	16.11	12.16	8.30	11.30
Soluble Reactive Phosphorus	0.24	0.26	0.26	0.28	0.13
± SE	0.03	0.04	0.04	0.04	0.03
Nitrate	0.04	0.05	0.05	0.06	0.03
± SE	0.00	0.01	0.00	0.01	0.01
Ammonium	0.49	0.30	0.40	0.36	0.35
± SE	0.11	0.04	0.06	0.03	0.03
Total Nitrogen (water)	0.13	0.18	0.23	0.05	0.08
± SE	0.04	0.03	0.05	0.00	0.01
Total Suspended Solids	590.40	725.00	1781.00	283.60	724.90
± SE	339.25	459.61	1442.00	188.00	467.1

Appendix 2: Mean values of different nutrients concentrations (mgL^{-1}) at different sampling dates in S1 along river Mereronyi wetland.

Date Variable	9/5/08	16/5/08	23/5/08	30/5/08	6/6/08	13/6/08	20/6/08
TP	0.51	1.1	0.89	0.2	0.62	0.23	0.23
± SE	0.03	0.01	0.03	0.03	0.02	0.03	0.01
pH	5.7	5.7	7.74	7.15	6.9	7.13	6.8
SE	0.37	0.18	0.09	0.09	0.3	0.08	0.01
NO_3	0.03	0.07	0.07	0.07	0.06	0.03	0.02
± SE	0.01	0.03	0.03	0.09	0.00	0.02	0.01
NH_4	0.23	0.3	1.74	0.06	0.25	0.27	0.39
± SE	0.02	0.02	0.26	0.08	0.01	0.025	0.03

Appendix 3: Mean values of different nutrients concentrations (mgL^{-1}) at different sampling dates in S5 along river Mereronyi wetland.

Date Variable	9/5/08	16/5/08	23/5/08	30/5/08	6/6/08	13/6/08	20/6/08
TP	0.16	0.53	0.07	0.18	0.38	0.18	0.1
± SE	0.02	0.03	0.01	0.00	0.03	0.02	0.02
pH	7.3	7.07	4.9	6.06	7.02	7.25	7.2
SE	0.18	0.2	0.5	0.36	0.06	0.09	0.17
NO_3	0.03	0.07	0.07	0.02	2.9	0.02	0.03
± SE	0.01	0.03	0.03	0.01	0.03	0.003	0.00
NH_4	0.23	0.49	0.4	0.07	0.2	0.24	0.49
± SE	0.05	0.04	0.03	0.03	0.02	0.03	0.03

Appendix 4: Maximum allowable concentrations of selected water quality variables for different uses, Chapman, (1992).

	Drinking water					Fisheries and aquatic life		
variable	**WHO**	**EC**	**Canada**	**USA**	**USSR**	**EC**	**Canada**	**USSR**
TDS mgL^{-1}	**1000**		**500**	**500**				
pH		**6.5-8.5**	**6.5-8.5**	**6.5-8.5**		**6.0-9.0**	**6.5-9.0**	
NH_4 mgL^{-1}					**2.0**	**0.005-0.025**	**1.37-2.2**	**0.05**
DO mgL^{-1}					**4.0**	**5.0-9.0**	**5.0-9.5**	**4.0-6.0**
NO_3 mgL^{-1}		**50**			**10**			**40**
PO_4 mgL^{-1}	**5.0**							
Faecal coliforms (no./100ml)	**0**	**0**	**0**					
Total coliforms (no/100ml)	**0.3**		**10**	**1**				

WHO	**World health organization**
EC	**European community**