EFFECTIVENESS OF SELECTED VEGETATION COVER TYPES AS SEDIMENT FILTERS: A CASE STUDY OF LAKE VICTORIA SHORE LINE, MAGU DISTRICT, TANZANIA.

By

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN LAND USE PLANNING AND MANAGEMENT OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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ABSTRACT

A study was conducted in Ihale Village, Magu District, Tanzania aimed to assess the effectiveness of selected vegetation cover types as Vegetative Buffer Strip Filters and their corresponding vegetation strip widths in filtering sediment delivery that are likely to enter the surface waters of the Lake Victoria from agricultural lands. Sediment laden runoff plots measuring 2 m by 20, 15, 12.5 and 10 m were established to determine the effectiveness of the selected filters and strip filter widths set at 10, 5 and 2.5 m against a standard width of 10 m which was planted with maize (*Zea mays*). The filters evaluated include elephant grass **(*Pennisetum sp*)** and Lemon grass **(*Cymbopogon citratus*).** Variables measured include: daily sediment for the rainy days, daily rainfall, infiltration rates, plant vigour of the filters (plant height) and percent vegetation cover. Data was analysed statistically using Excel, SAS and SPSS statistical packages. The results demonstrate that mass of sediment delivery through the tested filters decreases exponentially with increasing filter widths for all tested vegetation types with correlation coefficient (R^2) ranging from = 0.6 to 0.8. The trapping efficiency of the tested filters increases logarithmically with increasing filter widths. Sediment trapping efficiency increased from 54% at 2.5 m to 78% at 10 m vegetative filter widths for all tested vegetation types. A significant correlation exists between sediment delivery through elephant grass and lemon grass with filter strip width, percent vegetation cover and plant growth characteristics. About 30 to 40% of the observed variation in the prediction of sediment delivery through selected vegetation types could be explained by the percent vegetation cover alone. The study demonstrates that the tested Vegetative Buffer Strip Filters have the potential to purify water from sediment that has been transported into the riparian zone from the agricultural lands. Further research is recommended.

DECLARATION

I, Emmanuel Daniel Masanja do hereby declare to the senate of Sokoine University of Agriculture that this dissertation is my own original work and has not been nor concurrently being submitted for a higher degree award in any other University.

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The above declaration is confirmed

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LIST OF ABBREVIATION AND SYMBOLS

%	Percentage
≈	Approximately
ANOVA	Analysis Of Variance
asl	above sea level
BMPs	Best Management Practices
CLWIO	Cayuga Lake Watershed Intermunicipal Organization
cm	centimetre
DSSA	decision support aid
E	East
EAC	East African Community
EG	Elephant grass
E-W	East - West
et al	and Others
FAO	Food and Agriculture Organization, United Nations
FAO-WRB	FAO World Reference Base system for soil classification
GLM	General Linear Model
GPS	Global Positioning Systems
ha	hectare
HELB	Higher Education Loan Board
i.e.	That is
ICRAF	International Centre for Research in Agroforestry
kg	kilogramme(s)
km	kilometre
KY-31	*Festuca arundinacea* (tall fescue) grass variety
L	Litre
LG	Lemon grass
LSD	Least Significant Difference
LSMean	Least Squares Means
LULC	Land Use Land Cover
LVB	Lake Victoria Basin
LVEMP	Lake Victoria Environment Management Programme
LVI	The Lake Victoria Initiative
LVSLMM	Lake Victoria shoreline management model
m	metre
masl	meter above sea level
Max	Maximum
EESE	Encarta Encyclopedia Standard Edition
Min	Minimum
MSc	Master of science
MW	Mega-Watt
N	North
NEMA	National Environment Management Authority
No. Obs	Number of Observation

NPS	Non-Point Source
NPSP	Non-Point Source Pollutants
NRCS	Natural Resources Conservation Service
NTU	Normalized Turbidity Units
ORC	Ottauquechee Regional Commission
P	Probability
PRA	Participatory Rural Appraisal
R^2	Coefficient of determination
S	South
std	Standard deviation
SUA	Sokoine University of Agriculture
TE	Trapping Efficiency
TED	Trade and Environment Database
TM	Thematic Mapper
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
URT	United Republic of Tanzania
USDA	United States Department of Agriculture
VBSFs	Vegetative Buffer Strip Filters
VBSFW	Vegetative Buffer Strip Filter Width
VBSWs	Vegetative Buffer Strip filter Widths
VEO	Village Extension Officer
Vfsmod	Vegetative filter strip model
VFSMOD	Vegetation Filter Simulation Model
VFSs	Vegetative Filter Strips
VPO	Vice President Office

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

The Lake Victoria basin covers an area of 193,000 km^2 with Uganda occupying 16 %, Tanzania 44%, Kenya 22% and 18% is shared by Burundi and Rwanda (Yanda *et al*., 2001; Lufafa *et al*., 2003). The lake basin is used as a source of food, energy, drinking and irrigation water, transport, and as a repository for human, agricultural and industrial waste (LVEMP, 1996).

Population around Lake Victoria basin (LVB), which is growing over 3% annually, has exerted pressure on land resources leading to serious ecological and environmental degradation (UNEP, 2006). Increased pressure on land resources in the area has also resulted into steady/ceaseless changes in land use that may have impacted negatively on lake water quality and its ecological environment (Ssenteza and Kahembwe, 1998).

One of the most important environmental problems in LVB is soil erosion. Soil erosion a natural process commonly accelerated by human activities either directly or indirectly is reported to have significantly affected the geomorphology, ecology as well as water quality in the Lake Victoria Basin (Lufafa *et al*., 2003; World Agroforestry Centre, 2006 and Kimaro *et a*l., 2005). It is a major non point – source sediment pollutant that has raised both ecological and environmental concern particularly pollution of water bodies in many areas including Lake Victoria (Majaliwa, 1998).

Intensification of agriculture, expanding settlements and industrial development coupled with inappropriate land husbandry practices have largely contributed to the sedimentation and eutrophication of the lake leading to adverse effects on natural habitat, loss of biodiversity and reduced fish catches, thus threatening people's livelihoods (EAC,2004; LVEMP, 2004; EAC, 2006). While many studies have often shown that pollution in terms of toxic chemicals and waste is a serious concern, it is also true that sediment pollution in the LVB is a major problem, (Shepherd, *et al*., 2000; Lufafa *et al*., 2003; Nzomo, 2005; Kalibbala, 2005).

The magnitude of sediment pollution in Lake Victoria could be attributed to alteration of riparian areas sometimes referred to as riparian buffers zones through various land use changes and dynamics (Hecky and Bugenyi 1992; Scheren *et al*., 2000; Swallow *et al*, 2001; UNESCO, 2006; Twesigye, 2007). For example, UNESCO, 2006 reported that about 75% of the Lake Victoria wetland area has been significantly affected by human activities of which about 13% is severely degraded. Swallow *et al*. (2001) found that approximately 46 percent of the Nyando River Basin has experienced severe soil physical degradation due to human activities including agriculture, which has contributed to change in water quality of the Lake Victoria due to sediment loading into the lake.

Studies conducted by ICRAF (2006) on different land uses in the Kobong'o area in Kenya indicated significant land use dynamics whereby bush land covered an estimated area of 3.7% in 1948 had reduced to about 0.5% in 1967. The study shows further that riparian grasslands decreased from 70.3% in1948 to 36.8% in 2000, while farmlands doubled from 23.4% to 54.9% of the area respectively. The observed land use dynamics has resulted into high runoff, soil and nutrient loss from different land uses contributing to the poor water quality of the Lake Victoria. In Uganda it was estimated in the 1990s that an average of 7.3% of the original wetland had been converted to other uses. This ranged from as high as 43.2% and 40.3% for Jinja and Kisoro districts, respectively, to as low as 0% in districts such as Kalangala, Gulu, Kasese and Hoima, while the average figure for the districts having the Lake Victoria basin wetlands is 14.5% (Kasoma, 2003).

Alteration of natural transition zone (riparian buffers) around Lake Victoria has rendered the protective nature of these areas ineffective or even detrimental to the health of the lake water. These problems therefore can be reduced by managing or restoring vegetated riparian buffer zones around Lake Victoria shoreline. However, it is unfortunate that there is paucity of quantitative information on the appropriate vegetation cover types and width of the buffer zone that are effective in reducing sediment loading into the lake Victoria and other similar lakes in Tanzania and in East Africa in general.

Buffer zones of dense vegetation situated along the bank of a stream or lake (the riparian zone) are a simple and generally cost – effective method that can be used to protect water from polluting effects of sediment generating land uses (Dabney *et al*., 1993b; Chomachalow, 2000). Recently, it has been reported that vegetative filter strips (VFSs) are useful best management practice to reduce the amount of sediment, nutrients and pesticides leaving a field and entering surface waters (Thomas, 1997).

A vegetative filter strip is an area along a ditch, gully, stream, pond, lake, or sink hole that is covered permanently by vegetation such as grass, hay, or forest (Chesapeake Bay Program, 1995). According to Parsons, *et al.* (1994) grass filters and riparian buffers were effective in removing about 80-90% of sediment from storm runoff in the piedmont and coastal plain of North Carolina.

Research with both natural rainfall and rainfall simulators in Indiana, Virginia, Maryland and Iowa has shown for silt loam soils with slopes ranging from 3-12%, filter strips can remove 56-97% of sediment (Thomas, 1997). Many authors have reported that Papyrus grass can be an effective vegetation filter trap for mainly point – source pollution which originates mostly from the urban centres (Balirwa, 1998; Ojok, 2002). Some agricultural land uses such as cultivation of sugarcane are also reported to work as vegetation filters (Amegovu, 2002). Other studies have indicated that effective buffer filters are often provided by natural vegetation such as trees and associated woodland or forestry/grass association in the zone directly adjacent to the water way (Machiwa, 2002). Conclusions from these studies have shown that the effectiveness of the filter strips depends on the filter strip width (Welsch, 1991), shape and the area draining to the filter strip (Lowrance *et al.*, 1997), soil characteristics (Thomas, 1997), land slope (USDA-Natural Resources Conservation Service (NRCS, 1997) and the type and quality of vegetation (Vegetative Filter Strips, 1993). However, most of the researches conducted so far are in-field studies aimed at reducing sediments and runoff from cropland (Parsons *et al*., 1994; USDA, 1997). Therefore, there is a need to develop off-field soil loss control techniques which include the use of vegetation filter strips (VFSs) in order to reduce the amount of sediment leaving a field and entering surface waters like Lake Victoria.

National Environment Management Authority (NEMA) (wetland Act, 2000) in Uganda and the United Republic of Tanzania (URT) (Land Act, 1999) give a blanket recommendation of a buffer strip width as 200 m and 60 m respectively. However the buffering capacity is greatly influenced by vegetation density for the same slope – soil type combination (Kimaro *et al*., 2005). The given blanket recommendations also have important social economic implications given a near-landless farming community where every inch of land counts. Under such circumstances, where buffers satisfy both socio-economic and ecological demands, a win-win situation is required (Logan, 1990; Lefroy *et al*., 1999). Though many scientists agreed that a corridor of vegetation can become effective at buffering valuable aquatic resources from the potential negative impacts of human use of the adjacent land (Welsch, 1991), research is still required on the specific design criteria such as buffer width, types of vegetation and management for effective sediment filter around water bodies including lake Victoria. Therefore, this research focused on the need to investigate the role of vegetation cover types that could be effective sediment filters or buffers to be included in the riparian buffers zones around Lake Victoria shoreline. The important questions to be addressed are: which vegetation cover types are most effective buffer strips and what is the appropriate width of the buffer strip. Therefore, this research was aimed to assess the effectiveness of selected vegetation cover types in filtering sediment pollutant entering the Lake Victoria from agriculture lands.

1.2 Objectives

1.2.1 Overall objective

The overall objective of this study was to assess the effectiveness of selected vegetation cover types that can be used as sediment filters for establishment of buffer zones around Lake Victoria shoreline.

1.2.2 Specific objectives

(i) To identify potential land use/cover types for use as vegetation filter strips along the Lake Victoria shore line.

(ii) To determine the effectiveness of vegetation cover types and strip widths as sediment vegetation filters

(iii) To assess the factors likely to influence the effectiveness of the vegetation buffer strip filters for inclusion in the management of Lake Victoria buffer zone.

1.2.3 Research hypothesis

(i) Different vegetation types have the same effectiveness in filtering sediments

(ii) Different vegetation buffer strip filter widths have the same effectiveness in filtering sediments

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 An Overview of Lake Victoria Basin

2.1.1 General description of Lake Victoria Basin (LVB)

Lake Victoria is the largest fresh water lake in East Africa making second in the world after Lake Superior in the United States of America (Kayombo, 2006). It has a surface area of 69 490 km^2 with a shoreline, which is long (about 3,500 km) and convoluted, enclosing innumerable small, shallow bays and inlets including swamps and wetlands. Lake Victoria has a depth of about 80 to 90 m. The lake is shared between Kenya (6%), Uganda (43%) and Tanzania (51%) (Encarta Encyclopedia Standard Edition, 2004; EAC, 2006). The lake draws 20% of its water from the Kagera, Mara, Simiyu, Grumeti, Yala, Nyando, Migori and Sondu-Miru rivers, while the remaining 80% comes from rainfall. Mountains surround the catchment area on all sides except for the north (Yanda *et al*., 2001; Lufafa *et al*., 2003; UNESCO, 2006). Lake Victoria basin, receives a relatively high mean annual rainfall of 1200-1600 mm with a bimodal seasonal distribution which peaks in March-May and November-December (Conway, 1993; Nicholson, 1998).

2.1.2 Importance of Lake Victoria

Lake Victoria supports one of the highest rural populations in Africa, with densities of up to 1,200 persons per km^2 especially in parts of Kenya (Figure 1 and Figure 2) (UNEP, 2006). The average annual population growth rate around the Lake is estimated at 6% per annum in the urban centres and over 3% in rural areas (Ntiba, 2001).

Such growth rate exerts increasing pressures on the lake's natural resources (Yanda *et al*., 2001). More than 80% of the human population in the Lake Victoria basin is engaged in agricultural production, majority of which are small scale crop and livestock farmers. The main food crop is maize and cash crops are sugarcane, tea, coffee, cotton and horticultural products (Odada *et al*., 2004; Kayombo, 2006).

Lake Victoria with catchment area of 258,700 square kilometers provides employment for up to 30 million people (Olson and Berry, 2003). Lake's fish resources is an important economic source of foreign exchange which provides an annual landed value of 300-400 million US$ and supports nearly one-third of the total population in the East Africa region. The Lake provides an annual income ranging from US$ 90 to US$ 270 per capita to more than 30 000 people in the region (EAC, 2004; UNESCO, 2006).

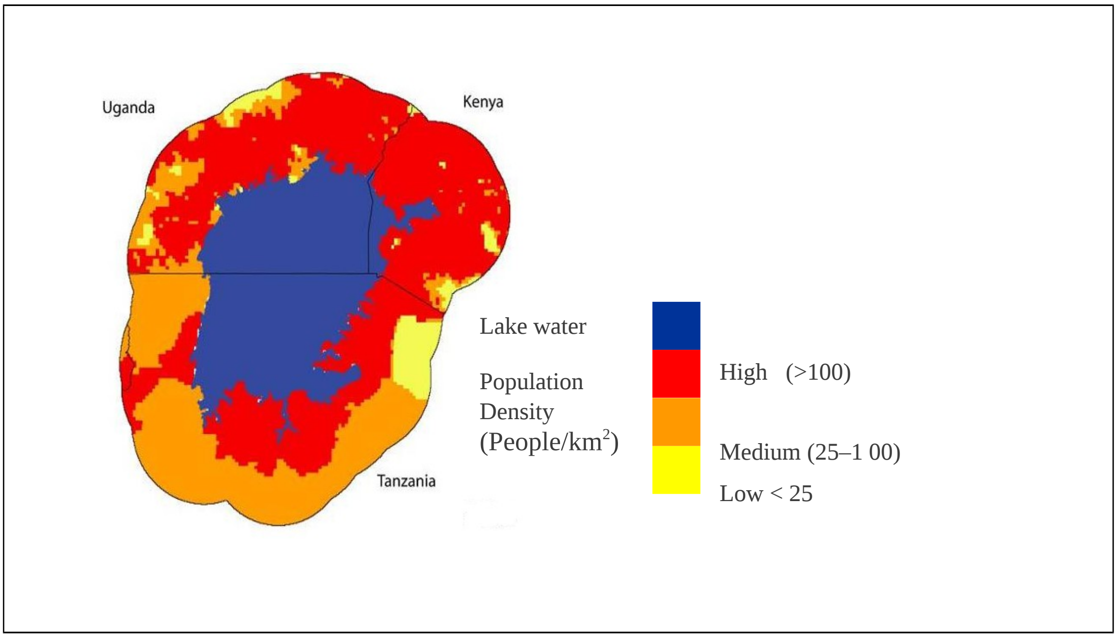

Figure 1: Population Growth around Lake Victoria

Source: Atlas of our changing Environment (UNEP, 2006)

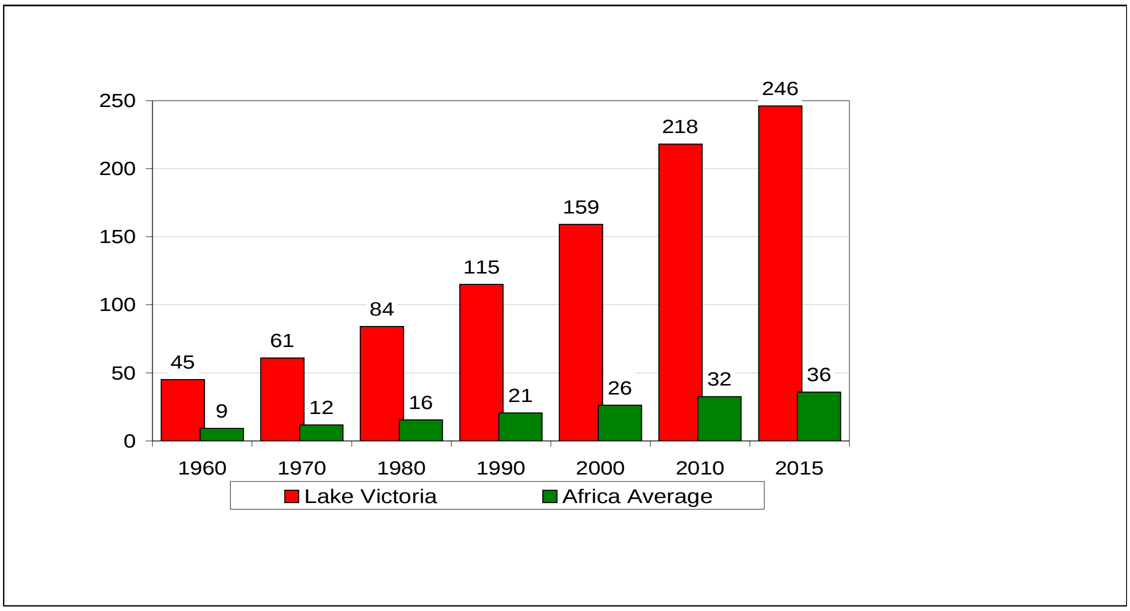

Figure 2: Population Growth: Lake Victoria vs. Africa

Source: Atlas of our changing Environment (UNEP, 2006)

2.1.3 Environmental problems facing Lake Victoria

Environmental problems facing Lake Victoria has been reported by many authors (Hecky, 1993; Shepherd *et al*., 2000; Scheren *et al*., 2001; Odada *et al*., 2004; Kayombo, 2006). Most of the problems reported by these authors include, forest and bush removal, overgrazing on wetlands, inappropriate cultivation practices on marginal agricultural lands i.e. agriculture on wetlands and on edges of river and lake water body, which has lead to unwanted sediment and stream flow changes that impacts the downstream human and natural communities. Scheren *et al*., (2001) indicated that the annual increase in cultivated land of 2.2% has a high impact on nutrient loading to the lake through sediment, thereby contributing to eutrophication of the Lake Victoria, while overgrazing by 1.5 million cattle and 1.0 million goats exceeds the sustainable grazing rate by a factor of 5.

The report by Hecky, (1993) and Shepherd *et al*. (2000) show that, as a result of human activities in the Lake Victoria basin including agriculture, water quality of Lake Victoria has changed. Decrease in water quality largely due to sediment and nutrient inputs from adjoining catchments has caused loss of genetic and ecological differentiation of aquatic species; such change has led to decrease in fish catch (Trade and Environment Database, 1996; Seehausen *et al*., 1997; Magunda *et al*., 1999).

Reported magnitude of soil erosion associated with various land uses (Table 1) in the Lake Victoria Basing is alarming ranging from about 45 t/ha/year to over 90 t/ha/year (Lufafa *et al*., 2003).

Table 1: The range of soil loss prediction

Soil loss predicted	
Land use	Amount t/ ha/year
Annual cropland use	93 t $ha^{-1}year^{-1}$
Rangeland	52 t $ha^{-1}year^{-1}$
Banana–coffee	47 t $ha^{-1}year^{-1}$
Forest and papyrus swamp	-

Source: Lufafa *et al*. (2003)

2.2 Riparian Zone of Lake Victoria Basin

2.2.1 Definitions and basic concepts

Riparian zones has been defined in many ways, but essentially it is a narrow strip of land that border creeks, rivers or other bodies of water (Shock, 2006). According to Owens (2003) riparian zone is an interface between terrestrial and freshwater ecosystems. Riparian zones is also recognized as a place of high diversity and unusual environmental processes such as, filtering out contaminants from groundwater, removing sediment and sediment-attached phosphorus by filtration, transforming nitrate to nitrogen gas, acting as a sink by storing nutrients for an extended period of time, providing a source of energy for aquatic life and retarding floodwaters (Lowrance *et al*., 1985; Gregory *et al*., 1991; Conroy, 2000).

2.2.2 Riparian buffers

Lowrance *et al*. (1985) define riparian buffers as a complex assemblage of plants and other organisms in an environment adjacent to water. Without definitive boundaries, it may include stream banks, floodplain, wetlands, as well as sub-irrigated sites forming a transitional zone between upland and aquatic habitat. In general riparian buffers are vegetated areas next to water resources that protect water resources from non point source pollution and provide bank stabilization and aquatic and wildlife habitat (Vose, 2002).

2.2.3 Types of buffers

Different types of buffers exist. From those politically implemented to scientific one's given different names in different places, regions or country, but their functions are much the same which include among others improvement and protection of ground water and surface water quality; reduction of erosion from cropland and stream banks; and protection of cover for livestock, wildlife, and fish (Dabney *et al.*, 1993b; Fischer and Fischenich, 2000; Wisconsin, 2002; United States Department of Agriculture, 2008). Some of the recognised types of buffers include contour Grass Strips, Riparian Buffers, vegetative filter strip, Grassed Waterways, Vegetative Barriers or narrow grass strips, some of these are described below.

2.2.3.1 Contour grass strips

Contour Grass Strips are narrow bands of perennial vegetation established across the slope of a crop field and alternated down the slope with strips of crops. Properly designed and maintained contour grass strips can reduce soil erosion, minimize transport of sediment and other water-borne contaminants (Fischer and Fischenich, 2000; Melville and Morgan, 2001). According to (Boubakari and Morgan, 1999) perennial grass such as Festuca ovina and Poa pratensis was evaluated in the laboratory experiment at the University of Silsoe, as contour grass strips for erosion control on steep lands for an erodible sandy loam soil on 21, 25 and 29% slopes where it was observed that, both grasses reduced erosion, with F. ovina being more effective in controlling erosion on the 21% and 25% slopes than on the 29% slope.

2.2.3.2 Riparian buffers

Riparian Buffers refers to Streamside plantings of trees, shrubs, and grasses that can intercept contaminants from both surface water and ground water before they reach a stream (United States Department of Agriculture, 2008). Riparian buffers constitutes what is known as riparian buffer strips mainly of resident vegetation laid out across the slope, predominantly comprised of grass species, also include other types of vegetation such as shrubs (Hook, 2003).

Riparian Buffer Strips is a linear band of permanent vegetation adjacent to an aquatic ecosystem intended to maintain or improve water quality by trapping and removing various nonpoint source pollutants (NPSP) (Fischer and Fischenich, 2000). Both grass buffers (vegetated filter strips) and forest buffers are increasingly used as riparian buffer strip to control nonpoint-source pollution from agriculture lands. These practices are supported by numerous studies that have directly measured the effect of buffer strips on water quality (Dillaha *et al.*, 1989; Magette *et al.*, 1989). A study conducted by Lowrance and Sheridan (2005), on the effect of a managed riparian buffer zone on sediment laden due to surface runoff at a research farm named Gibbs Farm Site, in the coastal plain at the University of Georgia show a maximum reduction of sediment ranging from 65 to 80%. The observed results are attributed to high filtering capacity of the riparian buffer zone. Sheridan *et al.* (1999)

observed similar results while conducting a similar study with grass buffer strip in south eastern United States.

2.2.3.3 Grass filter strips

Grass Filter Strips are used to intercept or trap field sediment, organics, and other potential pollutants before they reach a water body (Daniels and Gilliam, 1996; Hubbard *et al.*, 1998; Lee *et al.*, 2000, 2003). This type of filter strips are designed to reduce the amount of sediment reaching offsite water bodies (National Research Council, 1993). Yuan *et al*. (2002) while studying the effectiveness of various agricultural Best Management Practices (BMPs) in the Mississippi Delta observed that grass filter strips reduced sediment yield from 11.25 t ha^{-1} yr^{-1} to 9.25 t ha^{-1} yr^{-1} which is about 18% reduction.

2.2.3.4 Grassed waterways

Grassed Waterways refers to strips of grass seeded in areas of cropland where water concentrates or flows off a field. While they are primarily used to prevent gully erosion, grassed waterways can be combined with grassed filter strips to trap contaminants or field sediment (Mahler *et al.*, 2003; Mishra *et al.*, 2006). Fiener and Auerswald (2003) reported that grassed waterways have been widely used as part of conservation systems, to reduce runoff volume and velocity and sediment delivery. Briggs *et al*. (1999) through a study conducted in North American agriculture as erosion control practice found that grassed waterways reduced the volume of runoff by 47% when compared to non-grassed waterways. Hjelmfelt and Wang (1999) observed in Missouri that grassed waterway with a width of 9.9 m reduced the overall volume of runoff by 5%, peak runoff rates by 54%, and sediment yield by 72%.

2.2.3.5 Vegetative barriers or narrow grass strips

Vegetative Barriers or narrow grass strips are narrow, permanent strips of dense, tall, stiff, erect perennial grass vegetation established parallel and perpendicular to the dominant slope of the field. These types of strips are laid across a slope or along the contour at intervals that are sufficient to control soil erosion (Dabney *et al*., 1993b). Barriers form natural terraces (Dabney *et al*., 1999), which slow runoff and promote infiltration (Meyer *et al*., 1995) and enhance deposition of soil and organic matter (Melville and Morgan, 2001). Comparative study conducted at the University of Missouri's Bradford Center in Columbia, show that runoff was reduced by 15% when switch grass barrier was used while sediment reduction was 78% and 91% (Blanco-Canqui *et al*., 2004).

2.2.4 Importance of riparian buffers

Riparian buffer zones are used to protect water quality, stabilize stream banks, provide habitat for wildlife, and increase the overall aesthetics of an area (Shock, 2006). Naturally vegetated buffers literally hold the riverbank together and serve to protect it from erosion. These tracts of land also provide an important transitional area between waterways and developed land (Cooper *et al*., 1995; Naiman and Decamps, 1997; Shock, 2006).

Various researches indicate that excess sediments, pollutants, and debris are caught and filtered in buffer zones, preventing waterways from being over burdened. Up to 85% of excess sediment pollutants can be converted into less harmful forms by trees, shrubs, and grass in riparian buffer zones (Williamson *et al*., 1996). Studies in North Carolina reported that 84% to 90% of the sediment from cultivated agricultural fields was trapped in an adjoining deciduous hardwood riparian area (Cooper *et al*., 1987). Other studies in Little River in Georgia show that, riparian forest can accumulate up to 531 tones per hectare of sediment annually (Lowrance *et al*., 1986). Studies conducted in the Piedmont of North Carolina reported that grass and grass-forest filter strips were equally effective in removing sediments, reducing loads ranging from 60 % to 90 % (Daniels and Gilliam 1996). Cooper *et al*. (1995) reported from a study carried out near Taupo, New Zealand that "careful management of riparian zones" can allow buffering of streams from poor land use. Muscutt *et al*. (1993) observed that buffer strips can act as sediment and nutrient filters from agricultural fields. Other studies (Baltz and Moyle 1984; Barling and Moore 1994; Schultz ***et al*., 1994**; Natural Resources Conservation Service, 2003) have shown that riparian buffer zones represent a unique habitat for the community of plants and animals and can improve water quality by filtering out pollutants from surface water.

2.2.5 Importance of Lake Victoria Basin riparian zone

Lake Victoria contributes significantly in terms of physical, ecological, environmental, social and economical aspects. The lake acts as a sink for various rivers, the most significant being Kagera river discharging into the lake just north of the border between Tanzania and Uganda. The river contributes to about 7 percent of the total inflow (LVEMP, 1996).

Lake Victoria being a large water body plays a greater role in the hydrological cycle influencing precipitation in the riparian zone. However, 15 percent of Lake Victoria outflow acts as source of some rivers such as Victoria Nile which is the lifeline for much of Uganda, Sudan and Egypt by supporting extensive irrigated agriculture schemes in these countries (Kayombo, 2006). Water originating from the lake provides hydropower through its only outlet, the Victoria Nile River, at Owen falls in Uganda and other power plants further downstream. The two plants at Owen falls provide 260 MW of power, part of which is exported to Kenya (Kayombo, 2006).

About 21 million people in the Lake Victoria basin rely primarily on subsistence agricultural and pastoral production for their livelihoods (Swallow *et al*., 2001). These activities support provision of household food security and income for human population living in the area. Livestock production in this area serves as a main source of income supporting the agro-pastoral farming system which is predominant in the semi-arid areas along the lake where farming communities mainly operates subsistence mixed economies combining livestock and crop production (Swallow *et al*., 2001).

Riparian buffering vegetation (wetlands) of Lake Victoria also regulates the flow of water through their spongy underwater biomass and in the process contributes to water conservation. Wetlands are needed to anchor soils, catch silt, filter out pollutants and absorb nitrogen and phosphorus from the water flowing through the wetlands into the lake by incorporation into the tissues of wetland plants, and in the root zones of the aquatic plants (Balirwa, 2001; Kayombo, 2006). The wetlands in the Lake Victoria drainage basin constitute an important natural resource base upon which the communities living in the riparian districts depend for their livelihoods. In Kenya and Uganda, the Lake Victoria wetlands constitute about 37% and 13%, respectively, of the total wetland surface area in the two countries.

The riparian zone around Lake Victoria plays important roles to the lake ecosystem. It includes high aquatic and terrestrial biodiversity, i.e. species of flora and fauna which buffers the lake from various pollutants and used for crop and livestock production (Orach-Meza and Okurut, 2005). The zone harbors a number of biological features including fish, livestock, human population and plant species.

Balirwa *et al*. (2003) reported Lake Victoria as the largest inland water fishery sanctuary in East Africa. Fishery resources from the lake are a major source of revenue to governments and a source of employment, which supports livelihoods for 3 million persons who are directly involved in the fishery industry (EAC, 2006). It is estimated that the annual fish catch from Lake Victoria is about 750 000 metric tonnes, generating more than US$ 400 million per year of which, US$ 250 million in export. There are 1433 fish landing sites, 51 712 canoes and 153 066 fishers operating in the lake (EAC, 2006).

The riparian zone in some areas is used as a main source of tourism and recreation activities by supporting high populations of grazing wild game. This is the case of places like Serengeti National Park Plains in Tanzania. Most of the activities which are performed in this zone contribute to high National economic benefits. Studies done in three riparian states, Kenya, Uganda and Tanzania revealed to have a gross economic product of the lake catchments in the order of US$3-4 billion annually supporting an estimated population of 25 million people at incomes ranging between US$90-270 per capita per annum (LVEMP, 1996). Thus, the catchments contribute in livelihood of about one third of the combined populations of the three countries, and about the same proportion of the combined gross domestic product.

2.2.6 Problems facing Lake Victoria Basin riparian zone

There are many densely cultivated areas in the LVB, especially in Kenya, Rwanda and Burundi Table 2 (Scheren *et al*., 2000). Some rivers, such as the Sio, Nzoia, Yala, Sondu, Nando and Kuja in the LVB Kenya, drain highly productive agricultural areas. The sediment load of the Nyando River, for example, has increased by 7.5 times during the last 16 years, with turbidity measured at 527 NTU in the rainy season of 2001 (Swallow *et al*., 2002). This is due to rapid rise in human population in the Lake Victoria watershed which has put significant pressure on the environment. Vegetation in the watershed is being rapidly cleared for agriculture, firewood, charcoal and human settlements. Deforestation coupled with bad agricultural practices has exacerbated the problem of siltation in the rivers and lake, resulting in a degraded habitat for fish (Ntiba, 2001).The causes of rising pollution levels in the Lake are as many as they are diverse and each of the three East African nations is culpable (Scheren *et al*., 2000; Swallow *et al*., 2002; Verschuren *et al*., 2002; Magunda *et al*., 1999; Odada *et al*., 2004)

Table 2: Agricultural characteristics of Lake Victoria basin

	Catchment land area (1000 ha)		
	Cultivated	**Noncultivated**	**Total**
Kenya	1470	3400	4870
Uganda	1400	2100	3500
Tanzania	1500	5540	7040
Rwanda	930	1130	2060
Burundi	670	640	1310
Total	5970	12 810	18 780

Source: Scheren *et al*. (2000)

Over 70% of the population in the catchments area of the three riparian countries is engaged in agricultural production, mostly as small-scale farmers, for crops such as sugar, tea, coffee, maize, cotton, horticultural products, and livestock keeping (Kayombo, 2006). In addition, cropping areas often extend down to streams and lake edges, eliminating riparian buffering vegetation (wetlands). Furthermore, forested areas surrounding the lake have been cleared for settlement and agricultural activities (Gichuki, 2003 and Kayombo, 2006). Much of the forest cover and the wetlands, especially on mainland catchments, were severely degraded through excessive resource use by a rapidly rising human population. Vegetation dislodge in wetlands has caused soil degradation, finally leading to siltation and increase nutrient loading from rivers to the lake resulting into eutrophication of the lake (The Lake Victoria Initiative, 2006). According to Scheren *et al*. (2000), nutrient loads to Lake Victoria are associated mainly with atmospheric deposition and land runoff, which account for about 90 and 94 percent of phosphorus and nitrogen input respectively into the lake. Nzomo (2005) reported total phosphorus and nitrogen input in the lake standing at 3 860 and 77 200 tons per year respectively from land use. This is the major cause of progressive eutrophication in the lake.

Eroded soils from the catchment areas are transported through rivers to the lake. Water at the inlet is normally muddy or unclear due to shallow depths (Swallow *et al.,* 2001 and Olago *et al.,* 2007). Further observations indicate that tendency to concentrate farms along the riverbank is an increasing trend in Lake Victoria Basin. Studies conducted in Kobong'o village Nyando district show that, within 20 meters of the riverbank, cultivation has increased from 0.2% in 1948 to 12% in 2000 (Swallow *et al.*, 2001). Other wetlands area are deforested for wood fuel and other craft products e.g. Mukona, Mpigi, Amsha districts, Sango Bay in Rakai district and Mayuge district in Uganda. Although Uganda's wetlands are protected by law, yet most of it is still being reclaimed hence degradation. It is estimated that about 75% of the wetland area has been significantly reclaimed or transformed into other uses such as agriculture, gazing area, and artisan by human activity, and about 13% is severely degraded.

2.2.7 Land use/cover change in the Lake Victoria Basin

Land use/cover change due to exploitation of resources in LVB has been reported to be on the increasing trend (Hongo and Masikini, 2002; Lufafa *et al.,* 2003). Some reported case studies are presented below.

2.2.7.1 Land use/cover cover change for Rakai District, Uganda

Investigation conducted in Rakai to reveal land use/cover changes from 1954 to 1999 indicate that Savannah, Aquatic grassland and Forest/thicket has declined by 50%, 6% and 44% respectively, but there were no significant changes for Aquatic tree grassland. Papyrus swamps are rarely used for agriculture and currently they are conservation areas in Uganda under the Wetland Act, 2000. By 1999 Cropland has doubled at the expense of grassland, forest and thicket, as a result of increased agriculture from 6 500 to 30 600 ha, which is approximated to 370%.

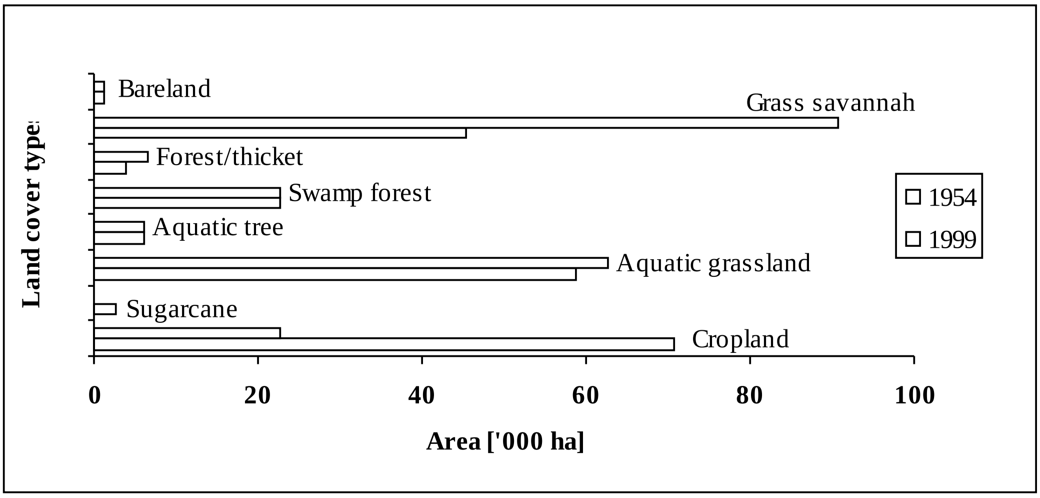

Figure 3: Land cover change for Rakai District, 1954 and 1999

Source: Isabirye (2005)

2.2.7.2 Land use/cover change in Mayuge area, Uganda

Land use/cover change studies conducted in Mayuge for 1960 to 1999 indicate that Savannah has decline by 79% but there was no significant changes for Aquatic tree grassland, while agricultural land has increased by117.2%. This growth is associated with transfers of forest, thickets and savannah cover to agriculture land. By 1999, annuals and perennial crops occupied 9% and 27% respectively and forest/thicket declined by 68%.

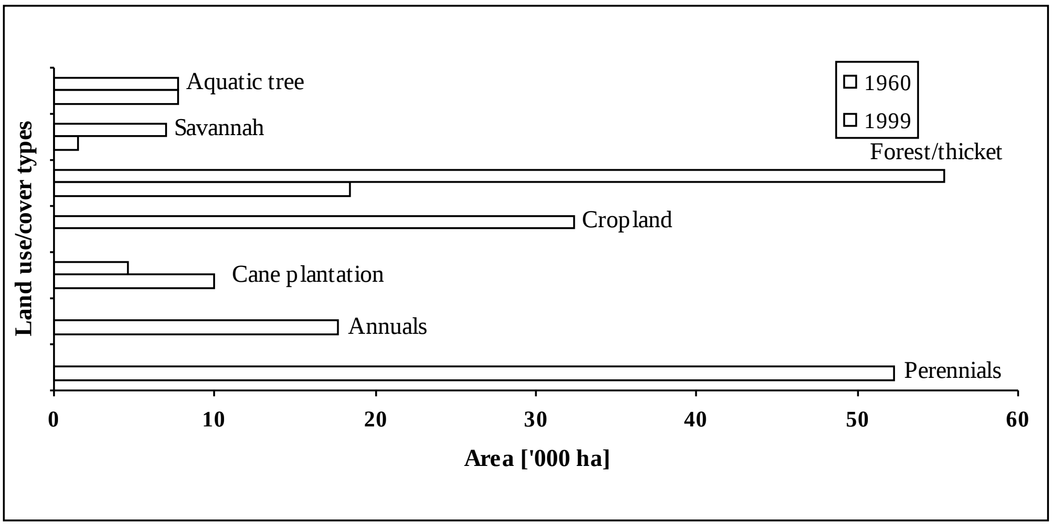

Figure 4: Land cover change for Mayuge District, 1954 and 1999

Source: Isabirye (2005)

2.2.7.3 Land use/cover change in Rongo area, Kenya

Aerial photographs of 1961 and digital images taken in March 2000 were procured for preliminary assessment of Rongo, area (Table 3).

Table 3: Land use change for Rongo sub-watershed (1961 to 2000)

Land use type	Approximate area of coverage (ha)		% change
	1961	2000	
Bushland	28.56	26.56	-7.0
Cultivated area	37.65	62.91	67.1
Grazing	70.99	43.46	-38.8
Homesteads	5.65	9.28	64.2
Paths / roads	0.70	2.16	198.8

Source: Shepherd *et al*. (2000)

Table 3 shows decrease of area under bushland by 7% in Rongo sub-watershed. This was mostly converted to cropping or trees were cut down for timber, building material or firewood. Cultivated area increased by 67%, grazing area declined by 38.8% and land under homesteads increased by 64.2% and this assessment reflect behavior of different land use systems in Rongo sub-watershed during the same period (Shepherd *et al*., 2000).

2.2.7.4 Land use/cover change in Mara Basin, Kenya and Tanzania

The Mara River is the lifeline of the transboundary Mara basin across Kenya and Tanzania (Mati *et al*., 2008). The basin is considered one of the more stable subcatchments of the Lake Victoria Basin and ultimately the Nile Basin. The basin contains forests, large-scale farms, smallholder farms, pastoral grazing lands, as well as hunter gatherers and fishers.

Table 4: Extent of Land use/cover change in the Mara Basin between 1986 and 2000

Land use/cover types	1986(km^2)	2000(km^2)	LULC Km^2	LULC (%)
Closed forest	892.7	688.6	-204	-23
Tea/Open forest	1072.9	1948	875	82
Agricultural land	1617.4	2503.5	886	55
Shrub and grassland	9593.8	7244.5	-2349	-24
Wetland	603.6	1394.4	791	131
Water body	54.2	55.6	1	3

Source: Mati *et al*. (2008)

The figures shown in Table 4 indicate that land use/cover change in 1973 for example, rangelands (savannah, grasslands and shrublands) covered 10 989 km^2 (79%) of the total basin area, which by 2000 had been reduced to 7245 km^2 (52%) while the forest areas were reduced by 32% over the same period (Mati *et al*., 2008).

Habitat changes through vegetation clearance for agriculture, settlements and plant harvesting for use as building materials, furniture crafting and fuelwood, etc., enhance erosion of the lakeshore and river channels and directly contributing to increased sediment and turbidity/suspended solids in the Lake Victoria (Yanda *et al*., 2001; Olago *et al*., 2007). Observing closely figures in Table 4, there are significant cover changes in the Mara Basin, and this is an indication that, formulation of remedial strategies is urgently required, to reduce the negative impact on land use/cover change facing the Basin. Such remedial measures could include introduction of vegetation cover in the riparian buffer zone of the Rivers and Lake Victoria shoreline to filter sediment pollutants.

2.3 Buffer Strips as Sediment Filters

The term 'buffer strip' is sometimes used interchangeably with filter strip, but filter strip has often been the preferred usage (Leeds *et al*., 1993; Wisconsin, 2002). However, for this research the term vegetative buffer strip filter will be used. Runoff may carry sediment and organic matter, and plant nutrients and pesticides that are either bound to the sediment or dissolved in the water. Filter strips (Figure 5) can help to remove pollutants from sediment runoff. In some cases, a filter strip can be used as pasture in a controlled-grazing, livestock management system (Lee *et al*., 2004).

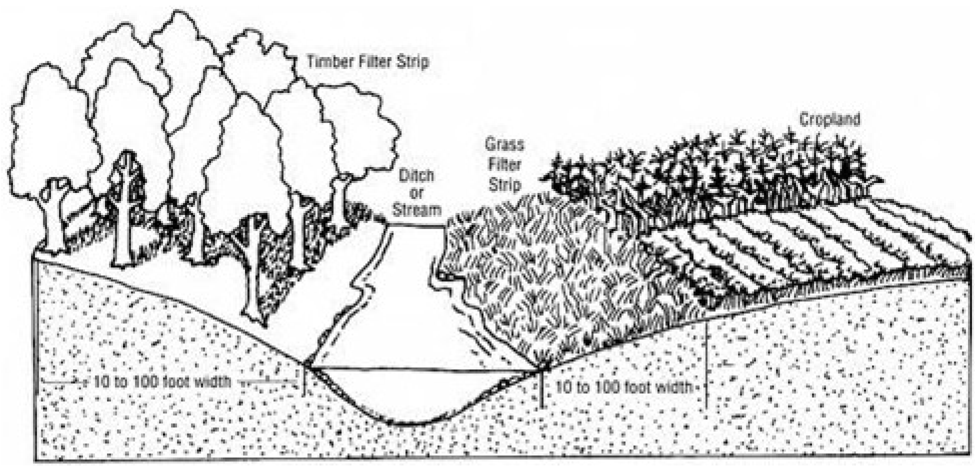

Figure 5: Vegetation filter strip

Source: Vegetative filter strip fact sheet (2006)

Various research works have been conducted to evaluate grass species, as vegetative strip filters to reduce runoff surface sediment laden (Dabney *et al*., 1993a; Dabney *et al*., 1993b; Young *et al*., 1980). Vegetative buffer strip filters planted in 5 to 15 m wide are reported to be effective in reducing sediment and nutrients from surface water at Mississippi State University (Daniels and Gilliam, 1996).

Recent studies focused on narrow vegetative filter strips of less than 1 m in Mississippi (Dabney *et al.,* 1993b; Rankins *et al.,* 2001) have shown an increase in infiltration and sedimentation in the upslope backwater created by vegetative filters. These indicate that the strips of vegetation grown as narrow strips have greater hydraulic resistance than same species grown as a sward, i.e. open space. This implies that such narrow vegetative strips could be used to buffer (sediments and increase infiltration) thus preventing inflow of sediment into the lake. Furthermore, where the land is scarce, the narrow strips can still be promoted to offer protection of sediment loading into the lake while maintaining the prevailing land use.

Several Studies have reported that both forest and grass riparian buffers can effectively trap sediment from agricultural lands (Norris, 1993; Dosskey *et al*., 1997; Wisconsin, 2002; Owens, 2003; NRCS, 2003). For example, research work carried out in Blacksburg, Virginia, show that orchard grass strips filter, 9 m wide removed 84 percent of the sediment and soluble solids from surface runoff, while grass strips 4.5 m wide reduced sediment loads by 70 percent (Dillaha *et al*., 1989). In the Coastal Plain of Maryland, KY31 tall fescue strips filter 4.5 m wide reduced sediment losses from croplands by 66 percent (Magette *et al*., 1989). Gilliam (1994) observed that narrow buffer strips in the Piedmont of North Carolina trapped 90% of sediment. Daniels and Gilliam (1996) found that 6 m wide grassed buffers and 13 m or 18 m wide combination of forest/grassed buffers reduced sediments by about 80%.

In Arizona, it has been observed that sand particles could be removed by grass buffer filters within a fairly short distance from the field edge (< 3 m), while the removal of silt particles required a buffer strip filter of 15 m (Wilson, 1967) The ability of the buffer filter strips to remove dissolved pollutants, such as nitrate, is highly variable and is specific to site's soils and hydrological characteristics (Daniels and Gilliam, 1996). Phillips (1989) while investigating the buffering capacity of various riparian soils in North Carolina observed that a buffer width ranging from 4.8 to 90 m is sufficient to remove nitrates from the field drainage. Often, widths ranging from 10.5 to 37.5 m are recommended to remove dissolved pollutants, depending on loads and site conditions such as topography slopes and source areas, and what is economically or politically practical (Palone and Todd, 1997).

2.4 Effectiveness of Vegetative Buffer Strips as Sediment Filters

Vegetative buffer strip filters are one of the agricultural best management practices that help to reduce sediment pollutants entering surface waters. These filters use natural processes to remove a portion of the sediment and other pollutants carried by surface runoff before the runoff enters a water-body. Norris (1993) observed in Australia that, the degree of effectiveness of the vegetative buffer strip filters to control water related pollutants is often influenced by site characteristics such as strip filter width, slope, vegetative cover, soil type and or the type of pollutant being carried.

Studies conducted on the piedmont slopes in Virginia USA show that, vegetative Buffer strip filters are most effective when the flow enters the buffer strip uniformly along its length in the form of overland sheet flow (Barling and Moore, 1994). According to these authors the sediment trapping performance is proportional to the sediment particle size. Other Research works, (Magette *et al*., 1989) conducted in Virginia, Coastal Plain of Maryland, and in the Piedmont of North Carolina reported trapping efficiencies which exceed 50% of the sediment and nutrients delivered when grass strips are used as filters.

For many years, researchers have studied various perennial grass species, planted perpendicular to the slope, as a means of reducing surface runoff and soil erosion

(Cayuga Lake Watershed Intermunicipal Organization, 2004 and Ottauquechee Regional Commission, 2007). Experiment conducted by Shaw and Murphy (2002) at Mississippi Agricultural and Forestry Experiment Station Black Belt Branch near Brooksville, demonstrated that 0.5 and 1m filter strips reduced sediment loss by 31 and 32%, though there was no significance difference between the two treatments. A study conducted in Iowa by Lee *et al*. (2003) to determine the effectiveness of an established Multi-species riparian vegetation buffer in removing non-point source (NPS) pollutants from agricultural areas show that riparian vegetation buffer and a layer of organic litter on the soil surface were more effective in slowing the velocity of surface runoff (Correll, 1997).

Wu *et al*. (2003) conducted a study in Iowa to compare the effectiveness of switch grass and tall fescue filter strips in removing the dissolved copper pesticide from runoff flowing at 0.0027 m^3 and 0.006 m^3 over 0.9 m soil surface area. The results demonstrate that about 60% of the applied copper was removed by both grasses from runoff at 0.006 m^3 flow rate, whereas with slow flow rate, 0.0027 m^3 all the applied copper was removed.

Experimental investigation conducted by Abu-Zreig *et al*. (2004) in Iowa on runoff reduction and sediment removal by VFS, demonstrated that the length of the buffer strip filter up to 10 m had the greatest effect on sediment trapping. Further observations indicate that sediment trapping efficiency decreased exponentially beyond 10 m strip, and that sediment trapping efficiency is inversely proportional to the inflow rates (Blanco-Canqui *et al*., 2004; Lovett and Price, 2004).

2.5 Factors Influencing the Effectiveness of Vegetative Buffer Strip Filters (VBSFs)

Factors influencing the performance of filters are numerous, including filter strip width, slope, grass density, type of vegetation, submergence of grass and characteristics of the inflow hydrograph and incoming sediments (Abu-Zreig, 2001). Despite of their significance, VBSF are still not widely adapted in the field due to lack of information on their effectiveness and corresponding influencing factors. It is also reported that processes involved in their studies are numerous and experimental studies can test only limited number of the parameters owing to physical constraints and financial limitations (Abu-Zreig, 2001). Some selected physical factors reported to have significant influence on the effectiveness of the VBSFs are discussed.

2.5.1 Vegetation type

Many studies have demonstrated that, structurally diverse riparian buffers, particularly those which contain a mix of trees, shrubs and grasses, are much more effective at capturing a wide range of pollutants than a riparian buffer that is solely trees or grass (Lowrance, 1992; Alliance for the Chesapeake Bay,1996; Eastern Canada Soil and Water Conservation Centre, 2002). Harden and Mathews (2000) conducted experiments in Copper Basin in southeastern Tennessee to compare rainfall infiltration, sediment detachment, and soil organic matter of reforested sites to those properties of unvegetated sites and forested reference sites outside the basin. Results of 54 rainfall simulations show that Soils in new “forests” had significantly less organic matter and lower infiltration than forests with more years old due to accumulation of litter which had improved soil structure. In New Zealand, a study by Smith (1989) found that retired pasture buffers of 10 to 13 m were capable of reducing suspended sediment and particulate nutrients in channelised surface runoff by over 80%. The ability of the buffer strip to retain sediment has also being reported from wetlands containing a large amount of standing vegetation and a large build-up of decaying plant litter (Gharabaghi *et al*., 2002). It is also reported that grass buffer strip, functions as source of organic matter for soil microbes that can metabolize non-point source pollutants.

Further research conducted by Schoonover *et al*. (2006) to compare sediment filtering capabilities of giant cane (Arundinaria gigantea) and forest riparian buffers in a southern Illinois, USA, using 3.3 m, 6.6 m, and 10.0 m width within the riparian buffers indicate that, significant sediment reductions had occurred within 3.3 m and 6.6 m in the cane and forest buffers, respectively. The giant cane buffer reduced incoming sediment mass by 94% within the first 3.3 m, while the forest buffer reduced sediment by 86% over 6.6 m. Within 10.0 m of the field edge, the cane and forest buffers reduced sediment mass by 100% and 76%, respectively. On a seasonal basis, cane buffer outperformed forest buffer. These results indicate that giant cane as ‘grass family’ is an appropriate species to include in the riparian buffer restoration designs for sediment control.

Also study conducted by Owino and Gretzmacher (2002) to investigate the performance of narrow strips of 16 m long by 2 m wide using Vetiver and Napier grass as barriers against soil loss on a clay loam soil at Egerton University in

Kenya, revealed that Napier and Vetiver grass strip plots reduces soil loss by 92 and 48 percent respectively. This signifies that, deposition of soil sediment along Napier grass strips was significantly higher compared with the Vetiver grass strips, thus can be used as vegetation filter to prevent inflow of sediment into the lake (Owino and Gretzmacher, 2002).

2.5.2 Slope

Report from various studies show that, as slope increases, the speed at which water flows over and through the buffer increases (Young *et al*., 1980; Peterjohn and Correll, 1984; Dillaha *et al*., 1989; Magette *et al*., 1989; Phillips 1989). The steeper the land within the Riparian buffer zone, the wider the vegetative buffer strip width (i.e. 8 to 9.25 m wide buffer of grass for 15% slope) is required to allow more time to slow the flow of water and absorb the pollutants and capture sediments within area.

Increased slope-steepness increases runoff velocity, resulting in decreased sediment deposition by vegetative buffer strip (Haan *et al*., 1994). Many researchers have reported that steep slopes i.e. areas which rises or falls at a sharp angle serve little value as a buffer, because runoff takes short time to pass through and recommend excluding areas of steep slope when calculating buffer width, otherwise greater width (> 30 m) may be required for grass vegetation, on steeper slopes, or where sediment loads are particularly high. The definition of "steep" varies from over 10% to over 40% slope (Dillaha *et al*., 1988; Barling and Moore, 1994; Collier *et al*., 1995; Wenger, 1999). Crossman and Robles (2007) of University of Virgin Islands

Cooperative Extension Service reported various Filter strip slope thresholds for effective sediment trapping. According to the authors cropland filter strips of 4.5, 6 and 7.5 m wide should have slopes ranging from flat to 10%, 10% to 20% and 20% to 30% respectively.

Dillaha *et al*. (1988, 1989) found that as slope increased from 11% to 16%, sediment removal efficiency declined by 7-38%. Trimble and Sartz (1957) in New Hampshire developed a relationship between buffer strip width and slope which is expressed by the following equation:

$$7.5 \text{ m} + (0.6 \text{ m}) (\% \text{ slope}) \qquad (1)$$

The Natural Resources Conservation Service (NRCS) has developed general guidelines for minimum filter strip width related to field slopes. These guidelines (Table 5) were developed for a drainage area to filter strip ratio of 30:1. It is recommended that width should be increased for fine-textured soil, if the vegetation stand is poor or if the drainage area to filter strip ratio is greater than 30:1 (Franti, 1997).

Table 5: Minimum filter strip width recommended by NRCS to field slopes for filter area ratio of 30:1

Field slope, %	Minimum width, (m)
< 1	3
0 -10	4.5
10 - 20	6

20 - 30	7.5

Source: Franti (1997)

2.5.3 Soil type

Soil type determines how quickly water can be absorbed. Soils that have high clay content and compacted are less permeable and have greater runoff. Alternatively, soils that are largely made up of sand drain water rapidly into the ground (Hawes and Smith 2005). Soil characteristics determine in large part whether or not overland flow occurs or how fast water and pollutants move to the stream. Generally, as soils become finer (clay) a wider (10 – 30 m) buffer is required to remove sediment and nutrients (Franti, 1997).

University of Nebraska- Lincoln (1997) evaluated filter strips using simulated rainfall and runoff on silty clay loam soils with 6 to 7 percent slopes and land area ratio of 6 ha of cropland to 0.4 ha of filter. Results indicate that 7.5 m wide grass filter strip can reduce off-site movement of total phosphorous by 85 percent. Also, Franti (1997) in Indiana, Virginia, Maryland and Iowa, reported that natural rainfall and rainfall simulators applied to filter strips under silt loam soils with slopes ranging from 3 to 12 percent, could remove 56 to 97 percent of sediment. Shiono *et al*. (2007) investigated the performance of a centipede grass (*Eremochloa ophiuroides*) strip in reducing sediment runoff in Okinawa, using experiments that were conducted on a clayey, fine-textured Haplic Red soil, and three strip lengths (0.5, 1.5 and 3.0 m) under natural conditions. The sediment removal efficiencies were 24%, 36 to 54% and 73% for three strips respectively.

Furthermore Abu-Zreig (2001) using Vegetation Filter Strips Model (VFSMOD), developed by researchers at University of North Carolina, reported that sediment trapping efficiency in Vegetation Filter Strips (VFS) is also influenced by soil type. Inflow sediment has a major effect on sediment trapping efficiency of Vegetation Filter Strips. The model calculated sediment trapping efficiency which shows that the trapping efficiency of clay sediments in a 15 m length of VFS was 47% compared with 92% for silt from incoming sediment.

Table 6: Efficiencies of some grass sediment filter at different soil types

Grass types	**Soil type**	**Efficiencies (%)**	**Reference**
Switch grass (*Panicurn virgatum*)	Silty clay loam	85	University of Nebraska (1997)
Perennial Ryegrass (*Lolium perenne* L.)	silt loam	56 to 97	Franti (1997)
Centipede grass (*Eremochloa ophiuroides*.)	Clayey	24 to 73	Shiono *et al*. (2007)
Vetiver (*Vetiveria zizaniodes* L.)	clay (Ferralsol)	94	Hussein ***et al*. (2007)**

2.5.4 Topography

Topography influence effectiveness of vegetative buffer strip filters. For example, in steep hilly terrain effectiveness of grass buffer strips as filters for sediment and nutrients is less than in rolling land, due to overland flow concentration in channelised natural drainage-ways. Dosskey *et al*. (2002) in Nebraska, USA studied the effect of concentrated flow on riparian buffers and its impact on sediment trapping efficiency. The author observed that Riparian buffers with an average width of 9-35 m in a field of 1.5-7.2 ha only 0.2-1.3 ha contacted runoff water due to the patterns of topography. Using mathematical relationships, Dosskey *et al*. (2002) estimated that, buffers could theoretically remove 41-99% of sediment if uniform distribution of runoff exist, but because of non-uniform distribution it was estimated that only 15-43% was removed.

2.6 Buffer Strip Widths

There is no definitive vegetative buffer width toward direction of flow, which is recommended to be effectively used for all areas (Green and Haney, 2005; Vose, 2002; Gharabaghi, *et al*., 2000; Hawes and Smith, 2005). Generally, 3 m buffer width can be effective in reducing sediment transport up to 90 percent. Other observations show that Buffer widths greater than 15 m are less effective in removing soluble contaminants. Effectiveness of properly placed/installed/planted (i.e. be comprehensively arranged along streams/Lakes and around pollution sources in a catchment) and maintained vegetative buffers can be greater than 70 percent and 50 percent for sediment and soluble pollutants removal respectively. In the validation of Vegetation Filter Strips Model (VFSMOD) Abu-Zreig *et al*. (2004) reported that length of VFS has the greatest effect on sediment trapping efficiency.

Grass filter strips are typically used for trapping sediment from agriculture land (White *et al*., 2007). Generally, such filter strips have been found to retain 80% or more of the sediment mass entering filter strips through runoff (Magette *et al*., 1989; Lee *et al*., 2003; Blanco-Canqui *et al*., 2004; Lowrance and Sheridan, 2005). For instance, Blanco-Canqui *et al*. (2004) while reviewing the sediment trapping efficiency of vegetated filter strips of different slopes and widths observed more than 80% of sediment was generally removed within 30 m when slope gradient of the field did not exceed 10%. Hook (2003) studied sediment retention in rangeland vegetated filter strips under controlled experimental conditions on slopes ranging from 2% to 20%. He reported that 94% to 99% of the sediment was retained in 6 m wide buffers regardless of herbaceous vegetation type (sedge, rush or bunchgrass**).** Abu-Zreig *et al*. (2004) evaluated sediment retention in filter strips of differing widths, slopes and vegetation types. They reported trapping efficiencies from 68% to 98% with an average of 84% at filter strip widths ranging from 2 to 10 m. In a study in Nebraska, it was observed that 15 m wide grass filter strips could remove delivered sediments up to 80% (Helmers *et al*., 2005).

Mannering and Johnson (1974) observed that sediment laden water delivered through 14.76 m strip of bluegrass found that 54% of sediment was removed. Dosskey *et al*. (1999) of University of Nebraska when compared performance of different filter strip designs, vegetation types and widths using simulated runoff on large plots having fine-textured soil and 6 to 7% slope, observed that Filter strips 7.5 and 15 m wide reduced about 76 to 93% of sediment in the runoff and 55–79% Phosphorous contaminants associated with sediment. A study by Abu-Zreig *et al*. (2004) of Jordan University on the efficiency of vegetation filters widths of 2, 5, 10 and 15 m long with a slope of 2.3 and 5% demonstrated that the average sediment trapping efficiency was 84%, ranging from 68% in a 2 m filter width to as high as 98% in a 15 m width when compared with only 25% for the control.

Length of the strip is considered in many studies as the most important parameter that affects sediment removal efficiency (Gharabhaghi *et al*., 2002; Lee *et al*., 2003; Abu Zreig *et al*., 2004). Studies reported by Mickelson *et al*. (2006) indicates that the sediment trapping efficiency of grass filters with length ranging from 1, 4-5 and 10 m down slope to be 50-60, 60-90, and 90-99 percent respectively. Gharabhaghi *et al*. (2002) while studying length ranging variations in sediment removal efficiency on vegetative strips from 2.44 to 19.52 m for a 1.22 m wide field with a slope 5.1 to 7.2% concluded that the first five meters play a significant role in the removal of the suspended solids and aggregates greater than 40 microns in runoff (Patty *et al*., 1997; Schmitt *et al*., 1999).

2.7 Policy Implications on Riparian Buffer Zones

2.7.1 Water resources

Water use Act No. 42 of 1974 of Tanzania, which has been revised in 1981, 1989, 1997 and 2001. Rule 8, No. 370 of 1997, state that it is prohibited to do human activities within 200 m from the river banks and 500 m from the lake and dam, and penalty is set for water polluters, (National Water Policy, 2002; Vice President Office, 2003)

2.7.2 Tanzania Land Act No. 4 of 1999

The Tanzanian Land Act gives a provision to isolate and protect water sources. The Land Act, Section 6(1) (b) and 7(1) (d) provide a buffer zone involving land within 60 m from river, river banks, Lake or beach announced by the minister of Land as hazardous land (National Land Policy, 1999).

2.7.3 Environmental management Act No. 20 of 1994

Environmental council and local government of Tanzania have authority to give directives and action to protect rivers, river banks Lake and shoreline. Tanzania

Environmental management Act No. 20 of 1994 Section 54 state that The Minister responsible for environment can in collaboration with other sectoral ministers, to declare through Government Gazette that river, river banks, Lakes shoreline a reserved area, and some project will be prohibited (National Environmental Policy, 1997; Vice President Office, 2003).

Looking at the policies and legislations discussed above each one gives a different buffer widths and lengths to protect the water bodies. There needs to harmonise the current buffer zone guidelines based on well researched scientific data regarding the type of vegetation to be used on the buffer zone, width, length and management.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Brief Description of the Study Area

3.1.1 Location

Lake Victoria basin, which is located between latitude 0.7° ′ N–3 ° ′ S and longitude 31.8° ′ E–34.8 ° ′ E (Ntiba *et al.*, 2001), is based at the upper reaches of the Nile River Basin with an altitude of 1,130 m. The study was conducted along Lake Victoria shoreline in Magu District, Tanzania (Fig. 6). The study area is located between longitude 33º 25’ to 33º 30’E and latitude 2º 25’ to 2º 35’ S, occupying an area of about 15, 000 ha.

3.1.2 Geology

According to Magu – Bunda geological report by Ishegize (2007), the area comprises the Nyanzanian lithologies, the dominant rock type is plagioclase amphibolities. Sin-tectonic acid platonic rocks of Precambrian time-scale exist and are sub-divided into granite and biotite granodiolite and underlie most of the southern part. Also Synorogenic rocks existing in this area have a well – developed system of jointing which is particularly evident on air photographs. The northern part of the area consists of heavy, dark, “mbuga” clay soils of Neogene age in an area thought to be underlain by both granitic and Nyanzian rocks.

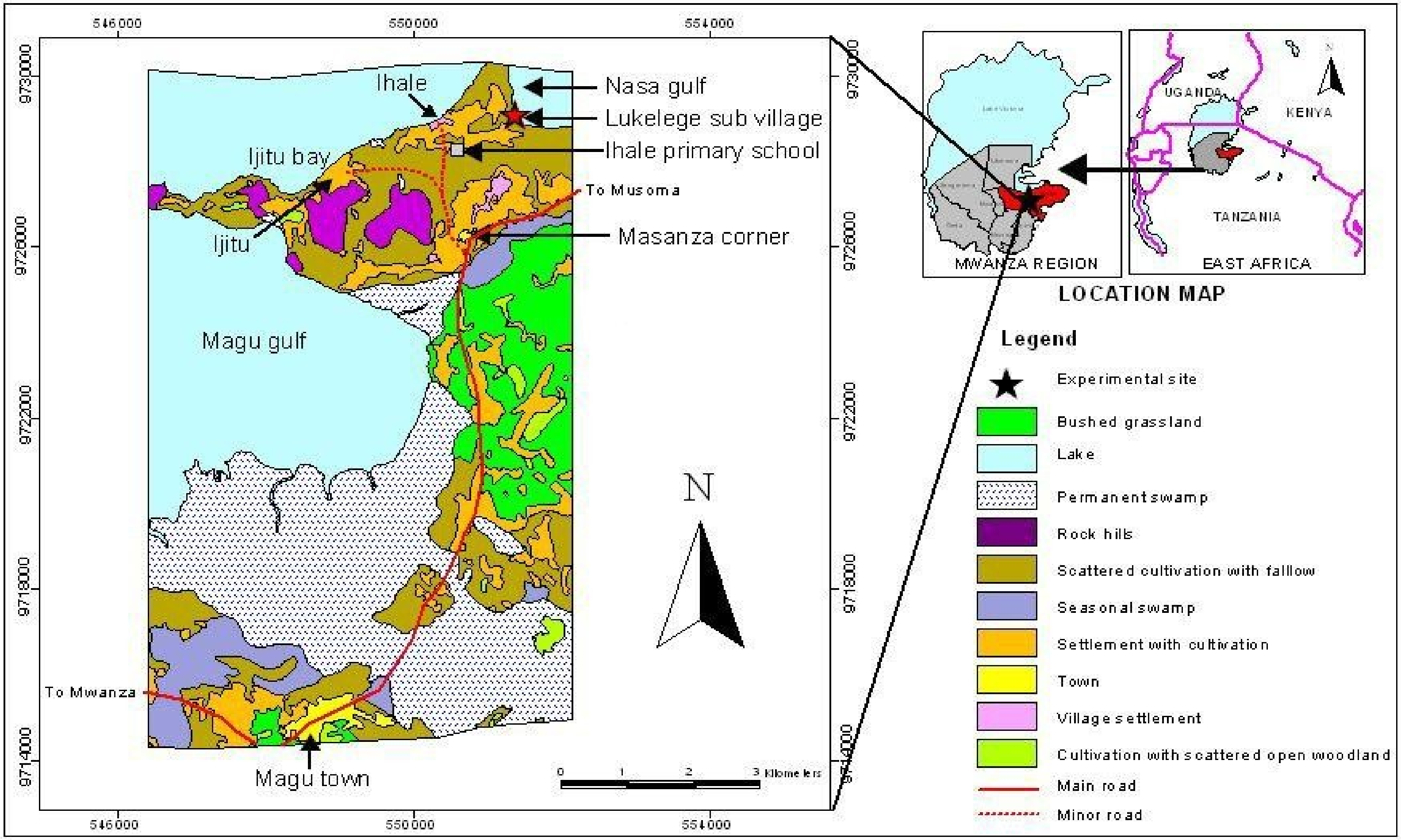

Figure 6: Location map of the study area

The emplacement of large granitic domes, E-W in orientation, indicate that the entire sequence appears to have been compressed from north to south, and this is one of an indication of the tectonic evolution / activity of the Tanzanian shield (Ishegize, 2007).

At study site the area consists of remnants hills and few rock outcrops of granite in origin. The rock outcrops are composed of hard rock that remains in place after surrounding material has eroded away. Chemical weathering processes peel away layers of rock, giving different formations characteristic and shape on residual hills and rocks outcrop.

3.1.3 Geomorphology

The landforms and landscapes consists of residual hills (inselbergs), gently undulating plains and lake terraces, with elevation ranging from 1140 to1180 m a.s.l and slope 2%-10% (Kimaro *et al.*, 2005). The most clearly features in the area is presence of extensive and mature land surface of Sukumaland. The area is drained with various tributaries emanating from the generally E-W flowing Ramadi River. All rivers in the area flow into the Duma or Simiyu River to the South that finally pours its waters into Lake Victoria. Outcrops in the area are scarce in some area is covered with extensive areas of recent alluvium and colluviums (Ishegize, 2007).

3.1.4 Soils

The soils follows typical Sukumaland catena consisting of Luseni/Itogolo/bambasi and Mbuga with a progression yellow-red “hill sands” to the poorly drained dark grey loam sands and clays of the valley bottoms, and low lying plains. The soil on the site are very deep, dark gray and brown, loamy sand/sand loam overlying slightly compacted sand clay/clay loam of 30 cm below soil surface. These soils are classified as Regosols (FAO, 1999).

3.1.5 Hydrology

Simiyu River discharges its water into the Lake Victoria, and is one of the major river basins carrying sediment pollutants into Lake Victoria (Crul, 1995).The catchment elevations of the Simiyu river range from 2000 to 1100 m at the outlet, and the river discharge at the catchment outlet ranges from 0 to about 200 m^3/s (De Smedt, *et al*., 2005; Rwetabula, *et al*., 2007). Simiyu catchment with 10 800 km^2 is considered to be one of the main contributors to the deterioration of Lake Victoria, because of many agricultural activities using agrochemicals (Ningu, 2000), and high yields of sediments (Lugomela and Machiwa, 2002). Seasonal river flow patterns determine pollution transport of the Simiyu River to Lake Victoria because the drainage is structurally controlled as they follow joints, shear zones and other internal structures such as foliation.

3.1.6 Climate

The site receives an average annual rainfall of 800 – 1 200 mm. Two rainfall maxima occur in the area, one in November – December and another in March – April. January and February usually have short dry spell. Potential evapotranspiration are high with values exceeding 1 500 mm per annum.

3.1.7 Vegetation and land use

The area is dominated by extensive grazing and intensive crop agriculture consisting of cotton, maize, cassava, sweet potatoes and rice as annual crops. Fishing is an important off farm activity in the area. Magu District consist of about 300, 000 heads of cattle where farmers keep them in large numbers. Cattle are grazed everywhere and no specific land allocated for grazing. Most of the natural vegetation has been cleared. The few scattered remnants of natural vegetation consist of aquatic grassland (papyrus grass, reads), elephant grass, shrubs like *Sesbania sesban*, acacia tree savannah, savannah grassland, wild palm, thickets and bushes.

3.2 Pre Field Work

During this phase the following tasks were carried out:

3.2.1 Collection of materials and relevant data

The materials for this research was obtained and collected from different sources as outlined below:

(a) Aerial photographs (AP) of 1991(scale1:60,000), and Topographical maps with scale of 1:50,000 (map sheet 34/2 (Survey and Mapping Division, 1979), sheet 22/4 and sheet 34/2) (Survey and Mapping Division, 1994)

(b) Mirror stereoscope

(c) Global Positioning Systems (GPS) instrument

(d) Landsat TM

(e) 5m and 30m measuring tapes and Hand held camera

(f) Gerlarch troughs for runoff and sediment collection and Iron plates labels for marking the treatments

(g) Buckets, Plastics bags, Sisal rope, and hammer

(h) Other information; Soils, land use (Kimaro *et al*., 2005)

3.2.2 Interpretation of maps, and aerial photographs

Interpretation of aerial photographs was done to identify historical land use/cover types for approximately 50 years starting from 1954 - 2004. The following tasks were carried out to obtain synthesized information for further GIS analysis:

- Visual interpretation of top maps (1:50,000) of 1979 and 1994 to identify land use/land cover patterns.
- Stereoscopic interpretation of aerial photographs of 1991
- Digitisation using ArcInfo and data integration using ArcView software to identify the historical land use /cover types that would be recommended for use as sediment filters.

3.2.3 Preparation of questionnaire for socio economic survey

Semi-structured questionnaires were prepared for gathering land use and socio-economic information and relevant land use/cover types potential for use as sediment filters. Random selection of contact farmers along Lake Victoria shoreline, were used to avoid biasness.

3.3 Field Work

3.3.1 Identification of potential land use/cover types for use as Vegetative Buffer Strips Filters (VBSFs) along Lake Victoria shoreline

This activity was basically carried to select vegetation cover types for use as buffer strip filters along Lake Victoria shoreline. Historical land use /cover types and social economic attributes were considered in the selection of VBSFs. During this phase the following activities were carried out.

3.3.1.1 Determination of historical land use/cover types

This activity was carried out using field survey, remote sensing and GIS techniques. Satellite images (Landsat TM), aerial photographs and topographic maps for the periods 1954 - 2004 were employed to obtain historical land use/cover changes that have occurred over time. Visual and digital classification of remote sensing data and field work was carried out to identify different classes of land use/cover and landforms-soil combination. Local people were involved to provide the local knowledge on the changes in land cover as a way to verify the observed results. In addition, landscape-soil-land use features were described according to FAO guidelines (FAO, 1999) for each major land use/cover type. Detection of changes in land use/cover was done using flow matrix analysis procedures (Stow *et al.*, 1980; Jensen, 1996). This activity generated data on historical and current land use/cover types which are potential for modelling the effectiveness of buffer strip filters and strip width in reducing sediment delivery into the lake.

3.3.1.2 Socio-economic survey

A socio-economic survey was undertaken and used to select contact farmers. Participatory Rural Appraisal (PRA) and semi-structured interviews were conducted in the study sites to assess farmers' opinions, establish historical land use/cover types that would be tested as sediment filter strips in the subsequent experiments. Informal interviews of key informants (elders, leaders, and other prominent members of the community) were carried out. Relevant data and information were gathered on general understanding of the communities; existed and existing major land use/cover types, main issues concerning the relationship between restoration of the lake environment and the living communities and elaboration on key issues over which there was confusion and lack of understanding. Agro-ecosystems were also described where dimensions of farmers' fields on different landscape-soil-land use combination were determined to provide farmers based information on different farm field sizes for use as a base for determination of Vegetative Buffer Strip Width (VBSFW) experiments.

3.3.2 Site selection for experiments to determine the effectiveness of selected as vegetation types as Vegetative Buffer Strip Filters and widths (VBSFs and VBSW)

This activity was carried out within 1 km off the lake shoreline, and was done based on information collected as summarized above and in collaboration with farmers and extension staff in the area (Fig. 7). The variables considered to select the site for experiment and vegetation filters to be used as treatments include historical and current land use/cover types, farmers' field plot lengths and soil-landform-land use setting. On the basis of these variables Ihale village in Magu District was selected as the pilot village to set up the experiment. The characteristics of the sites are given in (Table 7 and Fig. 8). On the basis of these criteria two vegetation types were selected for experimentation. The selected vegetation types include:

- Elephant grass (*Pennisetum sp*) - animal fodder
- Lemon grass (*Cymbopogon citratus*) - multipurpose use

In addition four vegetative buffer strip filter widths (VBSWs) i.e. 0, 2.5, 5 and 10 metres were established to determine their effectiveness in filtering sediment delivery from agricultural lands. The buffer strip filter widths were established based on minimum farmers field plot width obtained during land use and social economic survey as described in the previous sections above and as shown in (Table 8).

Figure 7: Participation of farmers on site selection for experiments to determine the effectiveness of selected vegetation types as vegetative filter strips and strip widths

Figure 8: Historical land cover types: Remnants of elephant grass on the Lake

Victoria shoreline

Table 7: Landscape/soil characteristics associated with different land use/cover types used for selection of vegetative buffer strip filters

Site	Landscape characteristics	Soil type		Soil characteristics	Land use/cover type
		Local name	Scientific name [FAO-WRB]		
Magu Tanzania	Landform: Lake terrace Elevation: 1140-1180 m asl Slope (%): 2-10	Itogolo	Regosols	Very deep, dark gray and brown, loamy sand/sand loam overlying slightly compacted sand clay/clay loam below a depth of 30 cm from the soil surface	Cotton, cassava, maize, groundnuts, sweet potatoes, rice, grazing, settlements, elephant grass, lemon grass,

m asl = meter above sea level; FAO-WRB = FAO World Reference Base system for soil classification

Table 8: Farmers plot length of selected land uses in the Lake Victoria shore line Magu, Tanzania

Agricultural land uses	Mean field plot length (m)	Standard deviation	Minimum	Maximum	No. Obs
Maize	66	11	52	77	12
Cotton	117	37	58	138	8
Cassava	70	10	56	79	11
Rice	43	26	17	85	15

3.3.3 Experiments to determine the effectiveness of selected vegetation types as Vegetative Buffer Strip Filters and widths (VBSFs and VBSW)

3.3.3.1 Experimental layout

A one hectare land was acquired from farmers for setting up experiments to determine the effectiveness of selected vegetation types as vegetative buffer strips filters and strip filter widths. On farm experiments were established under farmer management conditions with researcher working hand in hand with the farmers. The experiments were conducted to determine the effectiveness of selected vegetation types as vegetative buffer strip filters and their corresponding buffer strip filter widths. Eight individual bounded runoff plots measuring 2 m by 20, 15, 12.5 and 10 m were established of which four were planted with elephant grass and the other four with lemon grass, respectively at a strip filter widths of 10, 5 and 2.5 m against a standard width of 10 m which was planted with maize (*Zea mays*) which was set as a control. Note that the vegetative buffer strip filters were established before maize was planted on the standard plot. The idea is that the vegetative buffer strip widths planted with the selected vegetation types will receive runoff and sediment delivered from a standard 2 by 10 m plot planted with maize which is the dominant food crop grown in the studied site.

At the bottom end of each individual bounded runoff plot, Gerlarch troughs of 80-litre capacity were installed in a shallow trench (Sutherland and Bryan, 1989; Prasuhn, 1992, Kimaro *et al*., 2005) to collect runoff and sediment delivered from the maize plot through the vegetative buffer strip filters. The slope gradient of the terrain on the site was approximately 3%. The plots were bounded by compacted bunds of soil (30 cm high) on the upper and lateral sides sandwiching corrugated iron sheet in order to lead only the runoff of the bounded area into the Gerlarch troughs through the vegetative buffer strip filters. Land husbandry activities such as land preparation, planting and weeding on these erosion plots were strictly done in accordance with the usual farmers' practice. The treatments were arranged in split plot Design with Randomized strips filter widths replicated four times. The experiment was arranged as shown in Fig. 9 and Appendix 2.

3.3.3.2 Data collection

In order to determine the effectiveness of selected vegetative buffer strip filters, the following parameters were measured and monitored for two seasons from November 2006 to June 2007:

(a) Daily rainfall

(b) Daily runoff and sediment for the days with rain

(c) Infiltration rates

(d) Plant vigour of the vegetative buffer strip filters (plant height (cm)

(e) Percentage vegetation cover of the vegetative buffer strip filters

(f) Soil status (input-output) i.e. organic carbon, nitrogen, phosphorus and bases

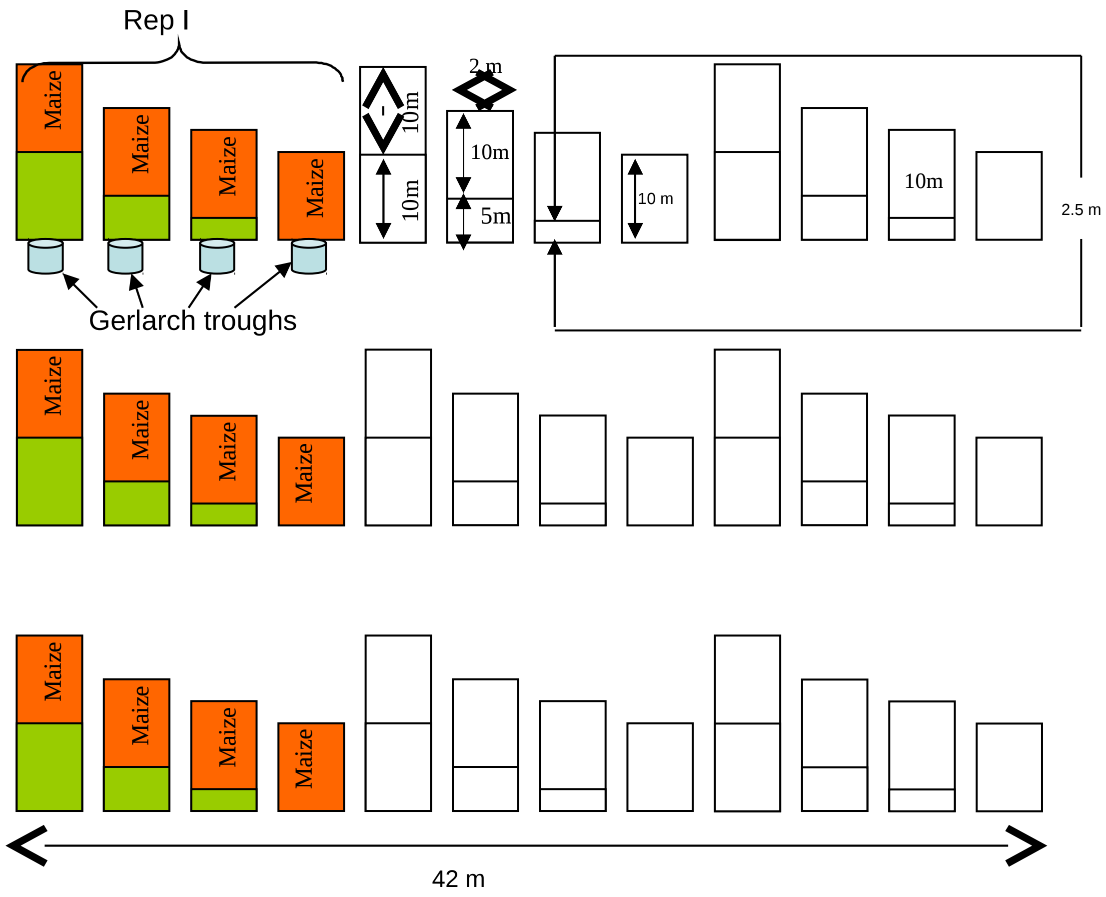

Figure 9: Experimental layout to determine the effectiveness of different land use/cover types and strip filter widths as sediment filters

3.3.3.3 Runoff and Sediments delivery

Runoff and sediments delivered in the Gerlarch troughs through vegetative buffer strip filters were collected on each day with rain. Both the volume of runoff and mass of sediments were determined. The volume of the runoff was estimated by multiplying height of its level in the Gerlarch trough with the cross-sectional area of the trough. Daily sediment delivery was determined on a one litre sub-sample after thoroughly stirring the contents in the Gerlarch trough from a given plot. Where the volume of runoff was less than one litre, the entire volume was taken as a sample. Each sample was left to settle and the sediments were obtained by decantation followed by air and oven drying respectively. The sediments were weighed and the cumulative weights were expressed on the basis of oven dry mass in kilograms (kg).

3.3.4 Assessment of the factors influencing the effectiveness of the vegetation covers types

3.3.4.1 Rainfall data

This was measured daily on each day with rainfall using a standard rain gauge installed approximately 2.5 km from the experimental plots. In addition, locally made rain gauge was installed at the experimental sites which enabled collection of rainfall data for comparison with records obtained from the standard rain gauge. Rainfall amounts per storm or groups of storms were recorded in every morning at 9:00 a.m. The data was measured to assess any influence of rainfall amount on capacity of the filters against runoff and sediment delivery

3.3.4.2 Infiltration rates

Infiltration rates were measured using double ring infiltration method following procedures as outlined by Landon (1991). The measurements were done on the experimental site in triplicate on three established stations which were placed at a radius of not less than 10 metres apart. The measurements were done to generate additional data for calculation of runoff delivery into the Gerlarch troughs through vegetative buffer strip filters.

3.3.4.3 Plant vigour (height in cm) of the vegetative buffer strip filters

Plant vigour was determined by measuring plant height of the vegetative buffer strip filters at an interval of 10 days to generate data for assessing any possible relationship between runoff and sediment delivery passing through the vegetation filters.

3.3.4.4 Percentage vegetation cover of the vegetative buffer strip filters

Percentage vegetation cover of the vegetative buffer strip filters was determined in accordance to the procedures outlined by Barry (1996) using a ring of 0.62 m in diameter and compared to Cover Estimator Chart (Fig. 10 and Fig. 11) to generate percentage vegetation cover data for establishing possible relationship between runoff and sediment delivery passing through the vegetation filters.

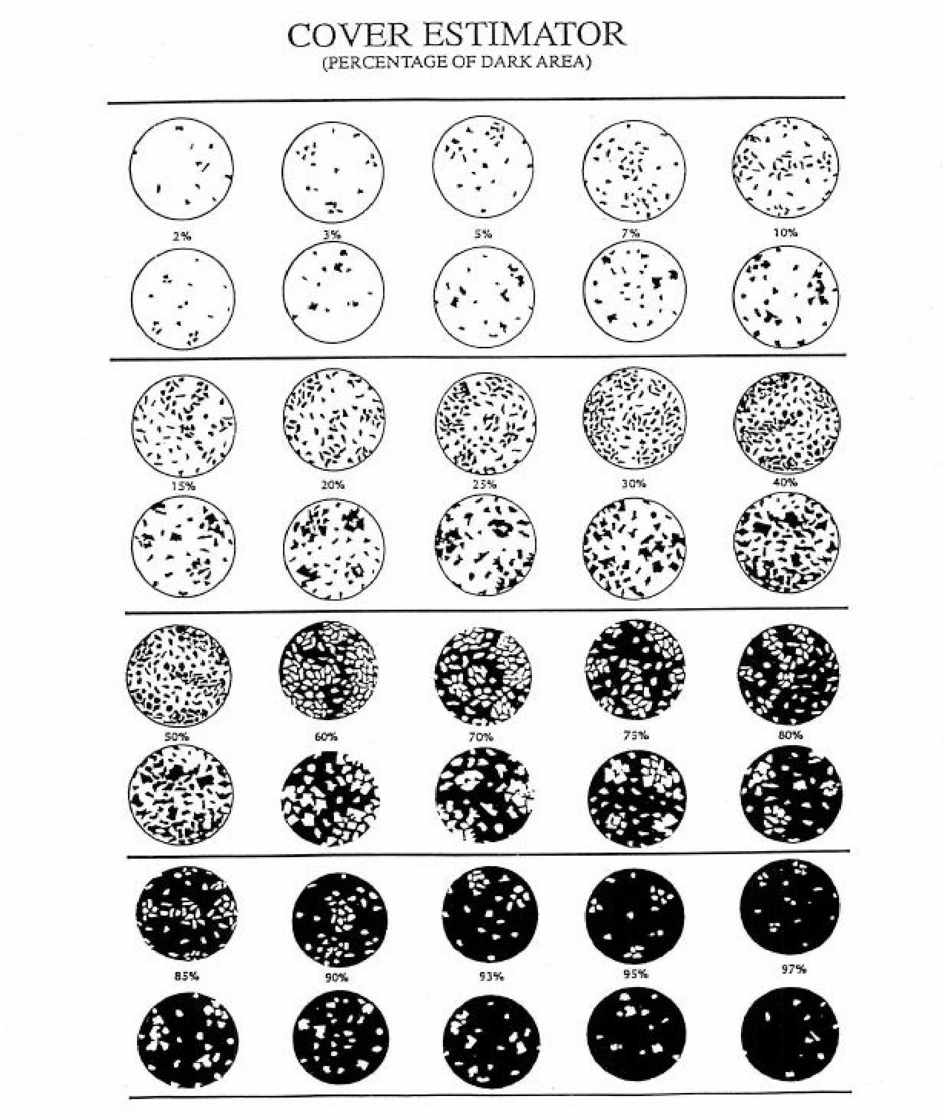

Figure 10: Cover Estimator Chart used for monitoring percentage vegetation cover of the VBSFs

Source: Barry (1996)

a b

Figure 11: Ring with 0.62 m diameter used to determine percentage cover of Elephant and Lemon grass respectively

3.4 Post Field Work

3.4.1 Data compilation

The collected data for the assessment of the effectiveness of vegetative buffer strip filters and their corresponding widths on runoff, sediment and soil attributes delivered in the sediments were compiled using spreadsheets in EXCEL and SAS, Tables and graphs.

3.4.2 Statistical analysis

Qualitative assessment and descriptive statistics were widely employed in the exploratory analysis of runoff and sediment delivery data and their corresponding related factors. This included the estimation of means and standard deviations of some critical variables of the study. Wherever it was applicable the degree of association between variables was measured by linear regression. Levels of significance (P) were obtained based on analysis of variance. The effect of multiple factors on runoff and sediment delivery for the treatments were statistically analysed according to the General Linear Model (GLM) of the Statistical Analysis System (SAS, 1999). Where appropriate, Least Squares Means (LS Mean) was used to compare the treatment means at 5 percent level of probability.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Identification of Potential Land Use/Cover Types for Use as Vegetative Buffer Strip Filters (Vbsfs) Along the Lake Victoria Shore Line.

4.1.1 Historical Land use/cover profile

4.1.1.1 Natural vegetation degradation

Historical Land use/cover profile from farmers' perception is presented in Table 9. Within the discussion groups, farmers reported land use/cover changes have occurred in the study site over the years. Plant communities and wild animals that existed in the past in abundance are now scarce commodities, and in case of wild animals, only small ones like antelopes exist. Important indigenous natural vegetation (multipurpose trees) like (*Albizia spp*) and *Muvule* (*Chlorophora excelesia*), are on the decline. Forests and thickets were associated with climbers and wild yams, which farmers resorted in times of food scarcity. Climbers were used for weaving baskets, fishing baskets and for making windows. These products are now scarce and expensive due to their reduced population. Spear and Elephant grasses are important multipurpose grasses commonly used in hut construction and grazing.

Farmers also *identified* the use of elephant grass as live bunds to control runoff and soil erosion. Today this species are very scarce and have made the construction and maintenance of thatch hats expensive. Also farmers identified and recognise the use of lemon grass as beverage and for medicinal purposes, but can be tested for erosion control. Farmers' perception on magnitude of natural vegetation degradation for the period 1954 to 2004 on the Lake Victoria shoreline is very high as shown in Table

10. Former forests and thickets have been degraded to farmlands and grasslands with scattered trees. An indication of deforestation or excessive tree cutting by farmers shows that farmers recognize the role trees play in conservation of biodiversity and soils.

4.1.1.2 Landing sites

Farmers' surveyed villages (Ijitu and Ihale in Magu District), indicated that only one landing site existed per village and fish harvests were very high by then. A tin of 20 litres was used as unit of measurement of fish harvest. Currently, the number of landing sites has increased substantially in all the studied villages ranging from 8 to 10 per village. The fish catch has also declined over the years. The increased number of landing sites, the number of fishermen and the poor fishing methods account for the significant changes in land use/cover. Most fish caught, e.g. the fatty *Nile perch*, require a lot of firewood to smoke. This activity has also enhanced the excessive cutting of trees in the neighbourhood of landing sites. These signify the relationship between the occurrence of landing sites and the land use/cover dynamics along the Lake Victoria shore line.

Table 9: Farmers land use/cover historical profile

Observation period	**Plant communities**	**Built up areas**	**Animals**
1954 to 1984	1. Forest and thicket: (*Albizia*), *emivule* (*Chlorophora excelsia*) 2. Wild yams 3. Climbers 4. Shrubs: *Sesbania Sesban* 5. Grssess: elephant grass, lemon grass, vetiver grass, and spear grass.	Few scattered villages and landing sites	Wild animals Elephants, Buffalo, Hippos, Hyenas, Warthogs, Antelopes and Kobs
1984 to 2004	1. Cultivated areas: mainly annual crops such as cotton, maize, cassava, sugarcane, sweet potatoes, groundnuts and rice 2. Grassland with scattered trees	Many villages and landing sites	Domesticated animals: cattle, goats, sheep, chickens and few small wild animals like antelopes

Table 10: Farmer perception on severity of natural vegetation degradation for the period 1954 to 2004 in the Lake Victoria shoreline

Observation period	**Respondent (%)**
Before 1954	12
1954 to1984	16
1984 to date	72

4.1.1.3 The agro-ecosystems and land use/cover change

Major crops grown by farmers reflect the effects of population dynamics (Table 11) on land use/ cover and farm size. Farmers indicated that there is an increase in farm size (Table 12), and increased cultivation of annual crops often as intercrops or mixed crops. According to farmers, cultivation of annual crops is considered more profitable and "sustainable" at subsistence level of production. In Magu district, increased human population and the number of cattle grazed has impacted on the current land use/cover dynamics as observed by most farmers in the area. In this area, livestock population density ranges between 5-10 animals/ha. Most of the grazing land i.e. the low lands which were used for extensive grazing have been converted to agricultural land for rice cultivation which is regarded as a cash crop in Magu district (Table 13). The immigration of people from other areas for fishing and other income generating activities may have also contributed to this transition but overall population pressure seems to account more for the changes in agro-ecosystems of the studied site.

Table 11: Population dynamics in Magu district, Tanzania

	Magu district		
Year	1968	1988	2002

Population	191 502	269 722	380 421

Table 12: Farmers plot length of selected land uses in the Lake Victoria shore line Magu, Tanzania

Agricultural land uses	Mean plot length	Standard deviation	Minimum	Maximum	No. Obs
Maize	66	11	52	77	12
Cotton	117	37	58	138	8
Cassava	70	10	56	79	11
Rice	43	26	17	85	15

Table 13: Farmer perception on land acreage change under smallholder rice cultivation for the period between 1954 to 2004 in Magu District

Land acreage change under rice	Respondent (%)
Increased	74
Decreased	12
Remain the same	14

Farmers indicated food security as their main objective and will only sell when there is surplus. This is clearly shown in Table 14 where farmers' preference ranking of agricultural land uses in order of importance show a significant shift towards annual cropping systems. They have also mixed feeling about the profitability of agriculture especially when it comes to production of cotton in Magu District. These observations are important and should be given due consideration in any intervention in the agro-ecosystem along Lake Victoria shore line during establishment of buffer zones width and buffer filters.

Table 14: Preference ranking of agricultural land uses in order of importance by respondents in Magu district, Tanzania

Agricultural land uses	Rank
Maize	5
Cassava	5
Cotton	4
Rice (paddy)	3
Sweet potatoes	2
Beans	1
Vegetables	1

4.1.2 Quantitative land use/cover change detection

4.1.2.1 Land use/cover changes in Magu District, Tanzania

Temporal periods, 1954 to 1984 and 1984 to 2004 had experienced considerable land use/cover transformations in Magu District, Tanzania. In these periods, all land use/cover classes, with exception of wetlands associated with papyrus grass have either profoundly decreased at the expense of other classes (Fig. 12). The class settlement has increased three times while savannah associated with fallow areas has decreased by 50%. This is an indication of a decrease in fallow period, an increase in area under cultivation and settlement attributed to increased human population. There has been considerable increase in the class rice cultivation over the past 40 years as it was also reported by farmers (Table 13). Major part of the lowland areas which formerly was used for grazing, cotton cultivation or left under fallow has recently been converted into rice production areas due to high market availability and profitable income to the farmers.

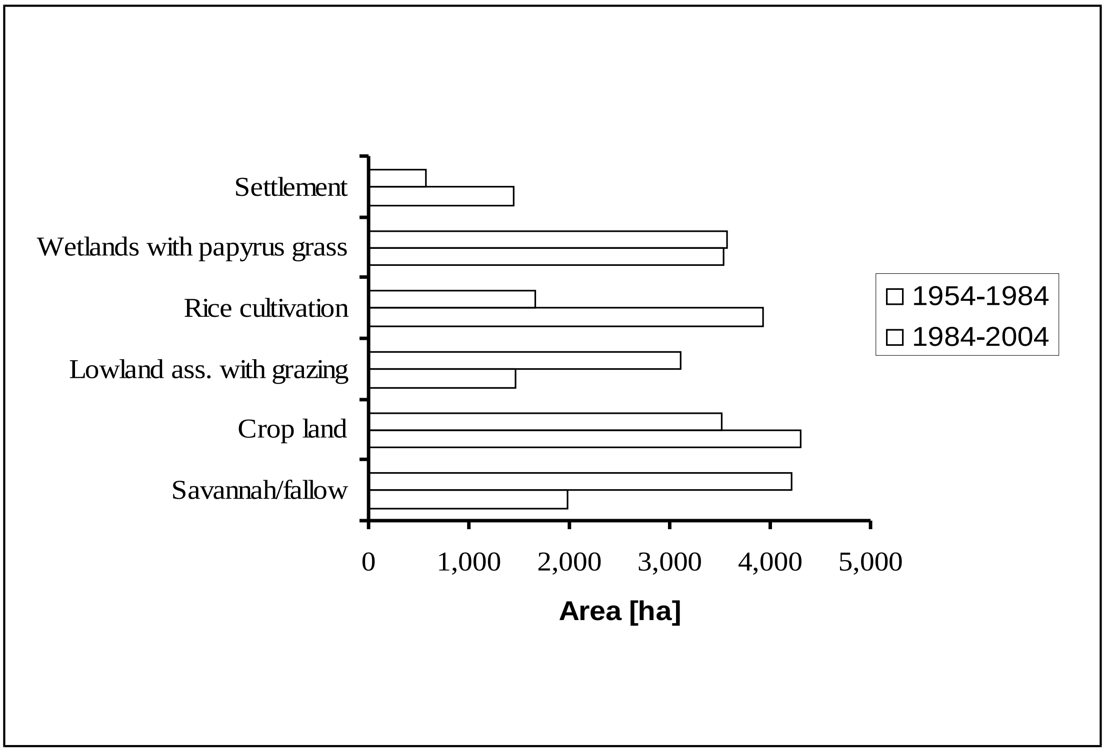

Figure 12: Land use/cover change for the period 1954 to 1984 versus 1984 to 2004 in Magu District, Tanzania

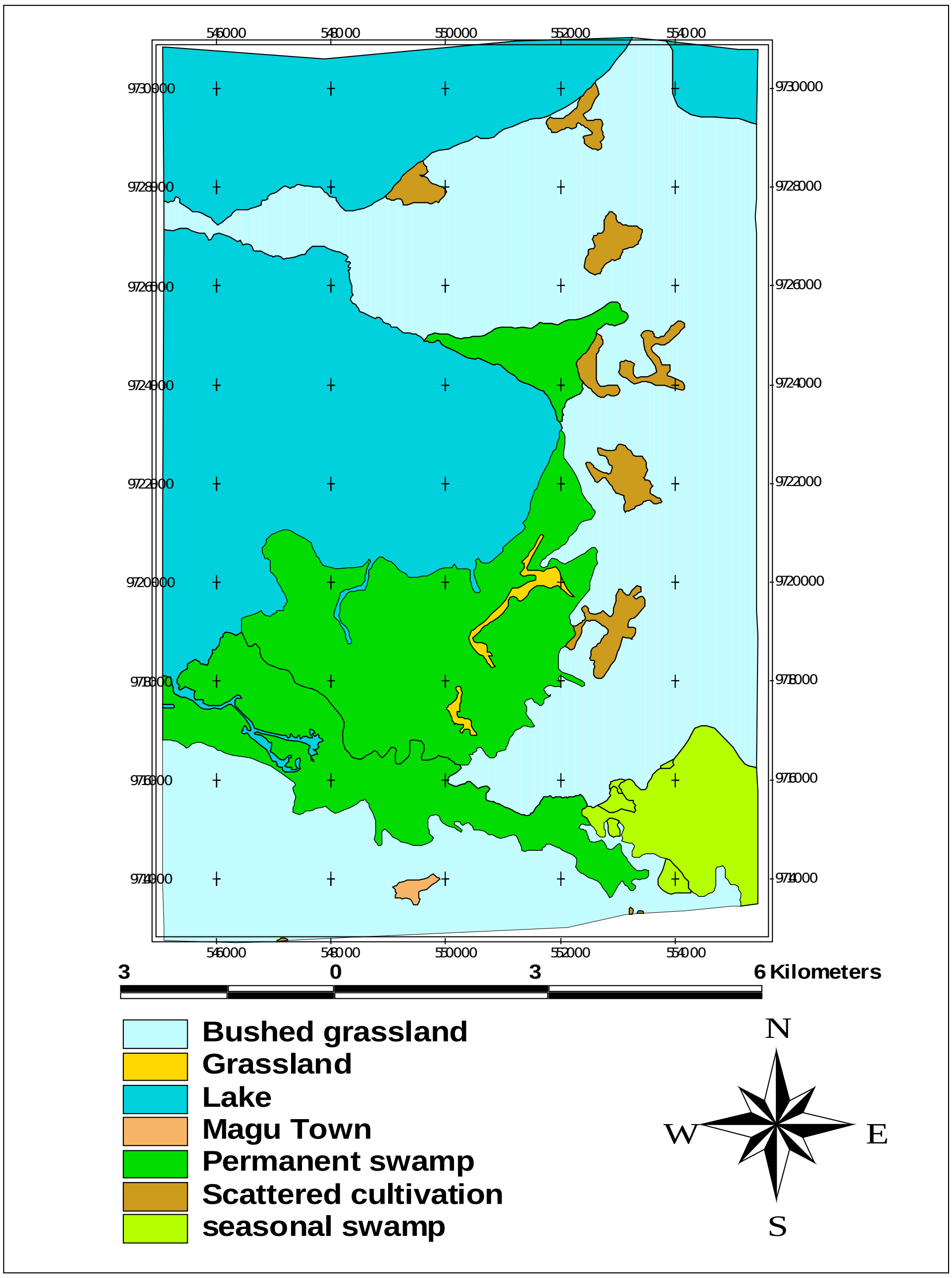

Figure 13: Land use/cover types existed 1979 in Magu District, Tanzania

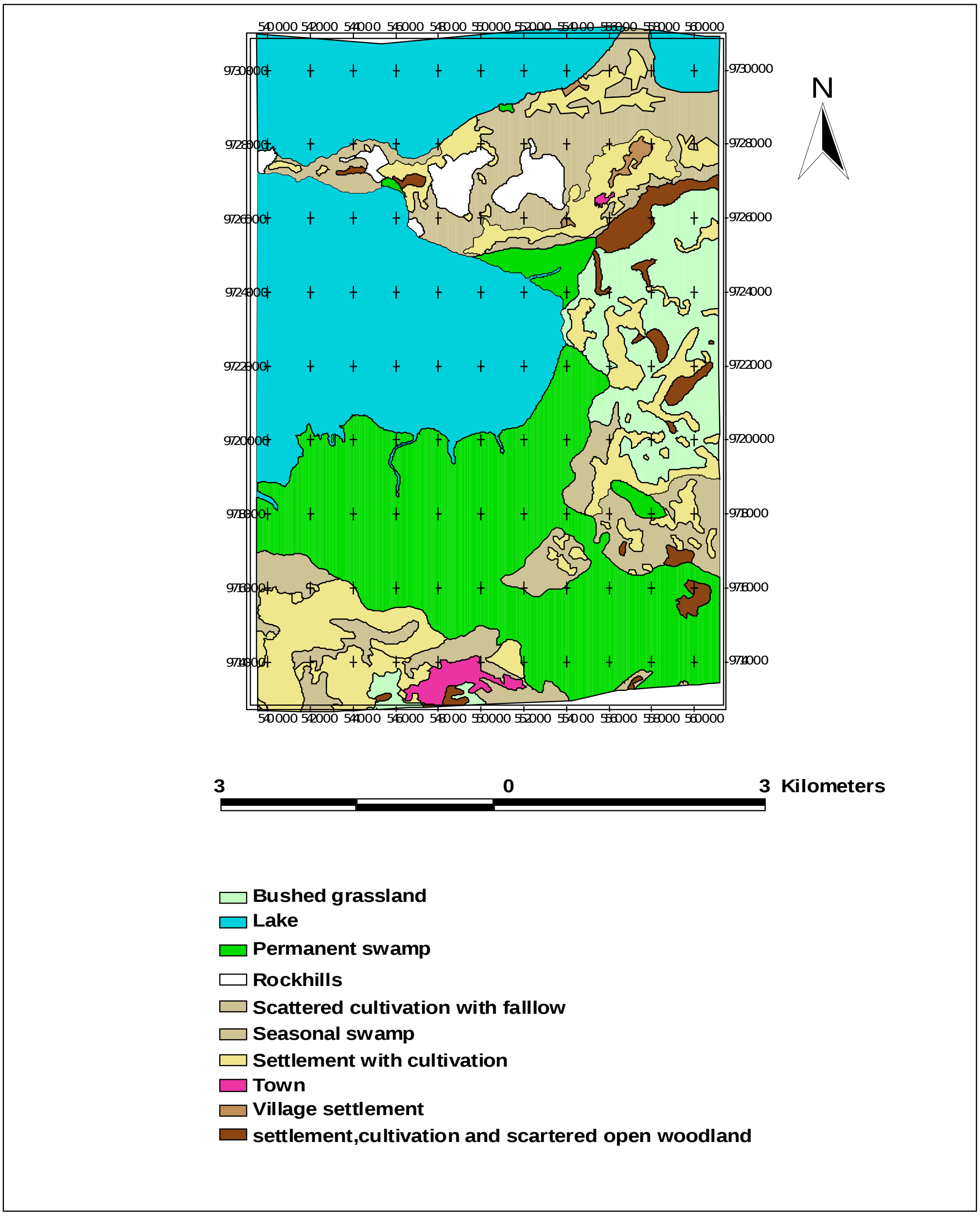

Figure 14: Land use/cover types existed 1994 in Magu District, Tanzania

The obtained results on land use/cover dynamics, show clearly that land use/cover have changed drastically in Magu districts over the last 40 years (Figure 12). Figure13 and 14 also show changes that have occurred between 1979 and 1994. This could be attributed to rapid human population growth and clearing of forest for agriculture and partly eradication of sleeping sickness diseases which is mainly caused by tsetse fly. Immigration from other neighbouring areas particularly the nomadic pastoralists also explains the observed trends. The nomadic pastoralist migrated into these areas, later became sedentary pastoralist and started crop cultivation in addition to grazing. This shift accounts for the major land use/cover changes observed along Lake Victoria shore line particularly expansion of cropland at the expense of grassland. Similar observations were reported by Hongo and Masikini (2002) and Kimaro *et al*. (2005).

The increase in both human and livestock population explains the encroachment on grassland and the forest and the rareness of fallow land along Lake Victoria shoreline. This has resulted in the shrinking of pasture land and a consequent increase in stocking rate above the normal rate. The current practice of seasonal burning of rangelands, coupled with high livestock population, explains the presence of thin and scanty grass cover, which barely protects the soil against runoff and erosion. High soil erosion rates (53.2 ton /ha /year) were observed by Majaliwa (2004) on a slopes of 22 % on these rangelands along Lake Victoria shore line. In some areas where better land use/cover conditions are practiced e.g. agroforestry less effect on soil erosion and hence sedimentation of the lake has been recorded (Muanuzi *et al*., 2003). These differences calls for proper evaluation of potential land use/cover types which can be recommended as sediment filters along the lake shore line. The historical land use information presented here has identified potential land use/cover types which provide a reference baseline for establishing relationships between land use dynamics and lake sedimentation.

4.2 Effectiveness of Vegetative Buffer Strip Filters (VBSFs) in Trapping Sediments

4.2.1 Magnitude of sediment delivery

The magnitude of sediment delivered by vegetation types tested as Vegetative Buffer Strip Filters (VBSFs) in Magu, Tanzania, is presented in Table 15 and Figure 15. The results demonstrate that mass of sediment delivery decrease exponentially (Figure 16) with increasing VBSF widths for all tested vegetation types in Magu District with correlation coefficient (R^2 = 0.6 and 0.84) (Table 16). The results show that, mean difference for VBSF width and vegetation types is significant at ($P \leq 0.05$). Also zero metre is significantly different from 2.5, 5, and 10 metre. However, sediment delivery from plots with VBSF widths of 2.5, 5, and 10 metre are not significantly different.

In an experimental study of grass filter strip (perennial rye grass), Gharabaghi *et al.* (2002) observed that the first 5 m of the filter strip were critical for sediment trapping. Looking at the results of this study it seems that amount of sediment trapped by VBSFs and their corresponding widths are significant up to a width of 10 metres. Similar observations were also made by (Abu-Zreig *et al*., 2004). However, the authors cautioned that the potential for the buffer to become clogged with fine sediment over time should be considered when establishing optimum buffer widths i.e. the vegetation recovery rate after clogging.

Table 15: Mass of sediment delivery at different VBSF widths in Magu District, Tanzania

	Lemon grass					Elephant grass				
	Sediment delivery [kg]					Sediment delivery [kg]				
VBSF width [m]	Mean	std	Min	Max	N	Mean	std	Min	Max	N
0	313.48	154.90	110	670	60	337.70	105.54	209	693	60
2.5	91.18	57.64	21	223	60	154.98	118.32	35	427	60
5	68.55	61.49	0	200	60	152.87	101.36	28	375	60
10	68.63	64.57	0	199	60	96.15	59.82	18	251	60

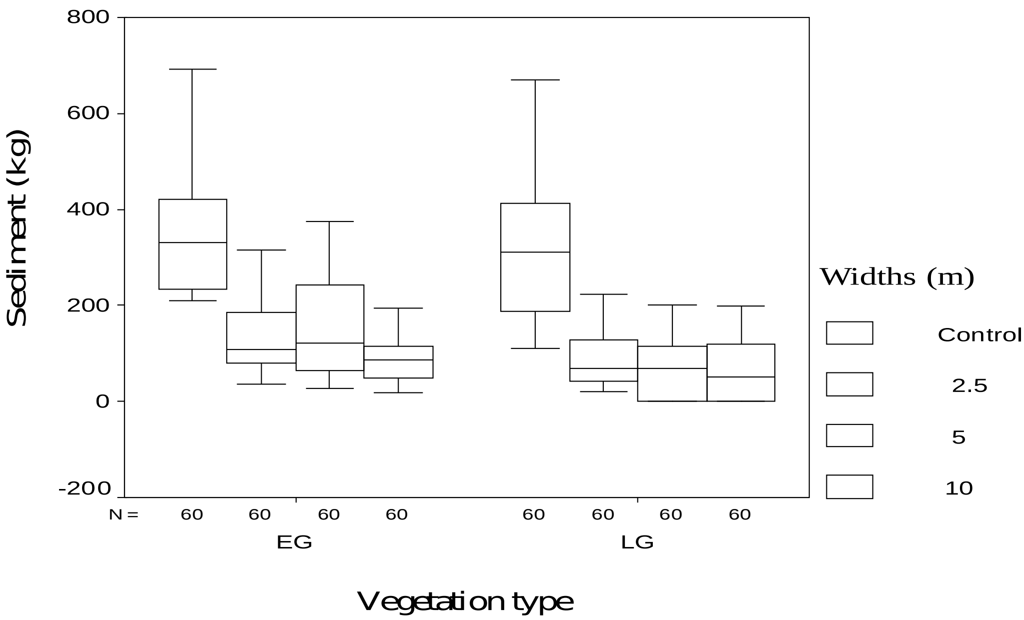

Figure 15: Box plot showing the magnitude of sediment delivery from different VBSFs in Magu District, Tanzania

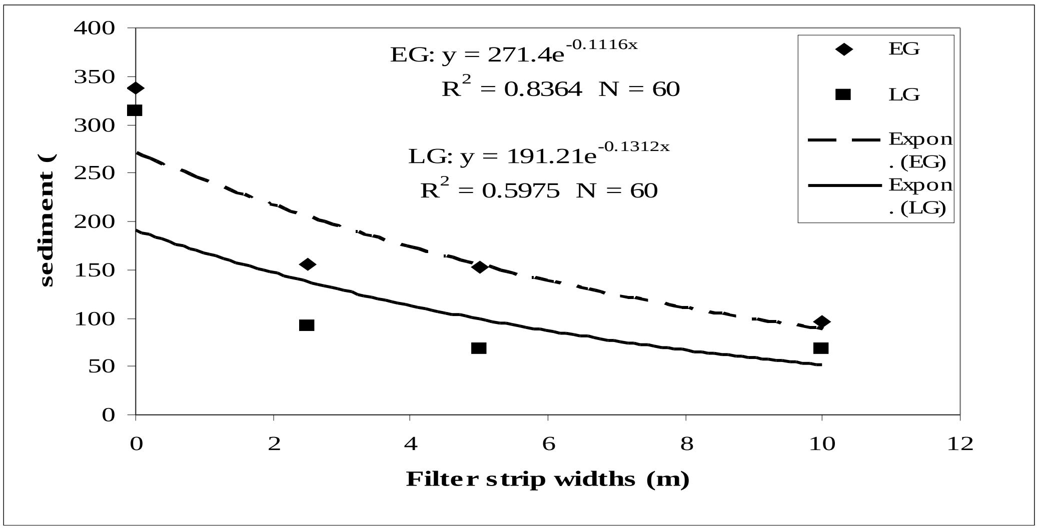

Figure 16: Relationship between sediment delivery and VBSF widths in Magu District, Tanzania

Table 16: Relationship between sediment delivery [kg] (Y) and VBSF widths [m] in Magu, Tanzania

Magu VBSF	Regression equation	Correlation coefficient	Number of observations
Lemon grass	$Y = 191.21e^{-0.1312x}$	$R^2 = 0.60$***	n = 60
Elephant grass	$Y = 271.29e^{-0.1116x}$	$R^2 = 0.84$***	n = 60

***=significant at 0.01

VBSF = Vegetative Buffer Strip Filters

4.2.2 VBSF trapping efficiency

Table 17 and Fig. 17 indicate the efficiency of the tested Vegetative Buffer Strip Filters in trapping sediment delivered from agricultural lands. The results show that trapping efficiency of the tested VBSFs increase logarithmically with increasing VBSF widths. Sediment trapping efficiency increased from 54 % at 2.5 m to over 78 % at 10 m VBSF widths for all tested VBSFs. These results agreed with previous authors (Young *et al*., 1980; Dillaha *et al*., 1989; Magette *et al*., 1989; Daniels and

Gilliam, 1996) who reported sediment trapping efficiencies exceeding 50% while studying the effectiveness of grass filter strips in trapping sediment and nutrient through laboratory using paddock grasses.

The main function of vegetated filter strips for sediment trapping is to provide flow resistance (through enhanced hydraulic roughness) that reduces the flow velocity and sediment transport capacity of surface runoff (Gharabaghi *et al*., 2002). These results demonstrate that Vegetative Buffer Strip Filters (VBSFs) like the lemon, and elephant grass, can be effective filters in removing sediment inputs to surface waters of Lake Victoria by restricting a minimum land area not exceeding 10 m under the tested VBSFs beside the lake shoreline and which will process water that has been transported into the riparian zone from the agricultural lands. This study concentrated on sediment transported by overland flow. There is a need to assess the contribution of concentrated flow at much wider scale to the overall sediment delivery into Lake Victoria riparian buffer zone.

Table 17: Efficiency of Lemon and elephant grass (VBSFs) in trapping sediment at different VBSF widths in Magu District, Tanzania

	Lemon grass		Elephant grass	
VBSF width (m)	Sediment delivered (%)	VBSF trapped sediment (%)	Sediment delivered (%)	VBSF trapped sediment (%)
2.5	29	71	46	54
5	22	78	45	55
10	22	78	28	72

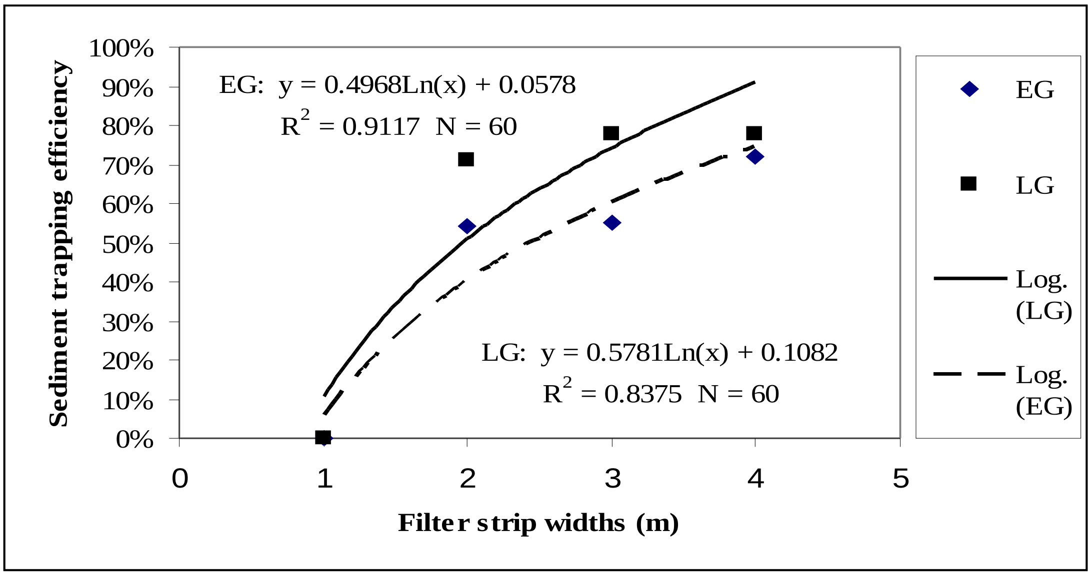

Figure 17: Plot showing the efficiency of lemon and elephant grass (VBSFs) in trapping sediment at different VBSF widths in Magu District, Tanzania

4.3 Some Selected Factors Influencing the Effectiveness of the Vegetative Buffer Strip Filters

4.3.1 Seasonal rainfall pattern

Rainfall pattern based on data recorded in Magu District, Tanzania between November 2006 and May 2007 are given in Table 18 and Fig. 18. The records show that the site received the highest rainfall in November (257.8mm) which contributed to about 53 percent of the total seasonal rainfall. In this site sixty three (63) storm events were observed in which a threshold level of 10 mm was found below which sediment laden runoff did not occur. These observations also show that the season was dominated by high frequency, low magnitude events than the infrequent high intense storms. Erosive rainstorms of 10 to 20 mm were most frequent. Only one rainstorm event exceeded 40mm, which fell on 16 May, 2007.

Table 18: Distribution of daily rainfall at the experimental site in Magu Tanzania from November 2006 to may 2007

Rainfall classes (mm)	Frequency	%	Cumulative %
1 – 10	35	55.56	55.56
10 – 20	10	15.87	71.43
20 – 30	8	12.70	84.13
30 – 40	9	14.29	98.42
40 – 50	1	1.59	100.01
Total	63	100.01	

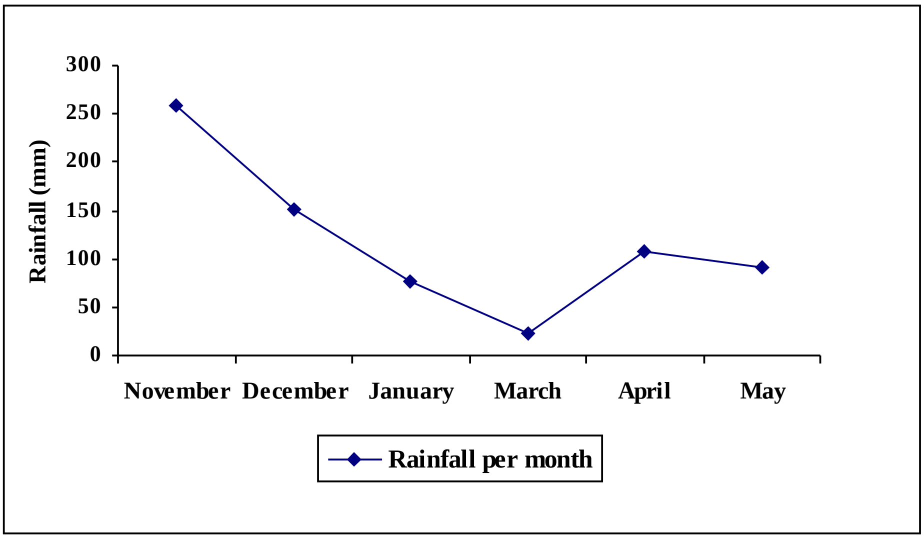

Figure 18: Seasonal (November 2006 to May 2007) rainfall pattern at the experimental site in Magu District, Tanzania

4.3.2 Influence of Vegetation percent cover on the tested Vegetative Buffer Strip Filters (VBSFs) in Magu District, Tanzania

The cumulative seasonal percent cover of the tested Vegetative Buffer Strip Filters (VBSFs) is given in Figure 19. The plot between sediment delivery and VBSFs indicate declining linear relationship of the sediment delivery with increasing percent vegetation cover and plant vigour. In Table 19 and Figure 20a and 20b, it is demonstrated that mass of sediment delivery decrease linearly with increasing VBSF percent cover for the tested vegetation types in Magu District with correlation coefficient (R^2) of 0.70 for elephant grass and 0.96 for lemon grass. Generally, in this study there was a strong positive correlation (P<.0001) between cover growth characteristics and plant cover percentage (Table 20) which implies that for Vegetative Buffer Strip Filters (VBSFs) to be effective a dense vegetative structure is an important factor to consider.

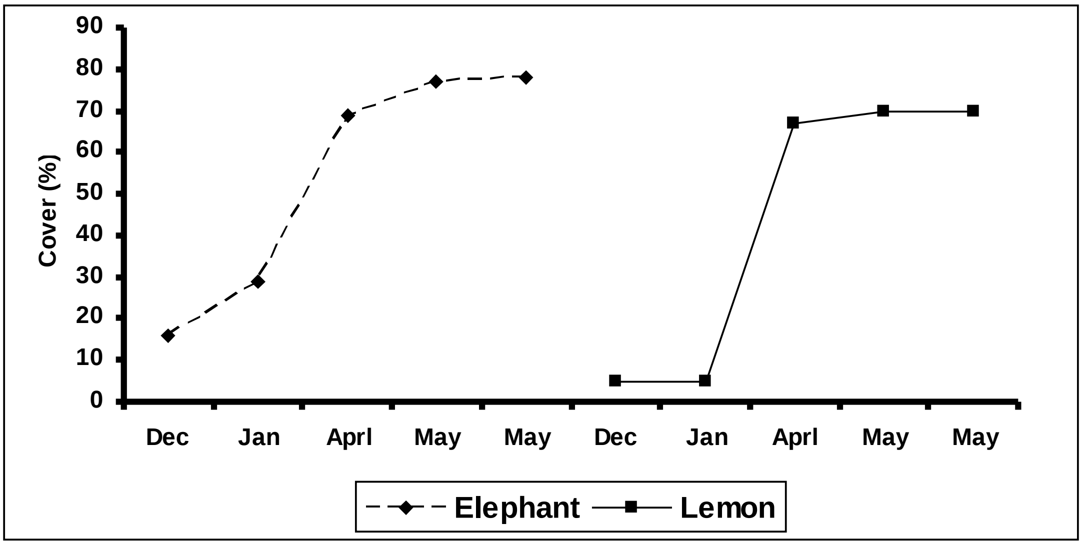

Figure 19: Cumulative seasonal percent cover of the tested VBSFs in Magu, Tanzania

Table 19: Relationship between sediment delivery and VBSF percent cover in Magu, Tanzania

Vegetative Buffer Strip Filters (VBSFs)	Regression equation	Correlation coefficient
Elephant grass	Y = -0.1008X + 70.161	0.6996
Lemon grass	Y = -0.4199X + 68.193	0.9622*

*significant at 0.05

Where Y = mass of sediment delivery (kg), X = percent VBSFs cover

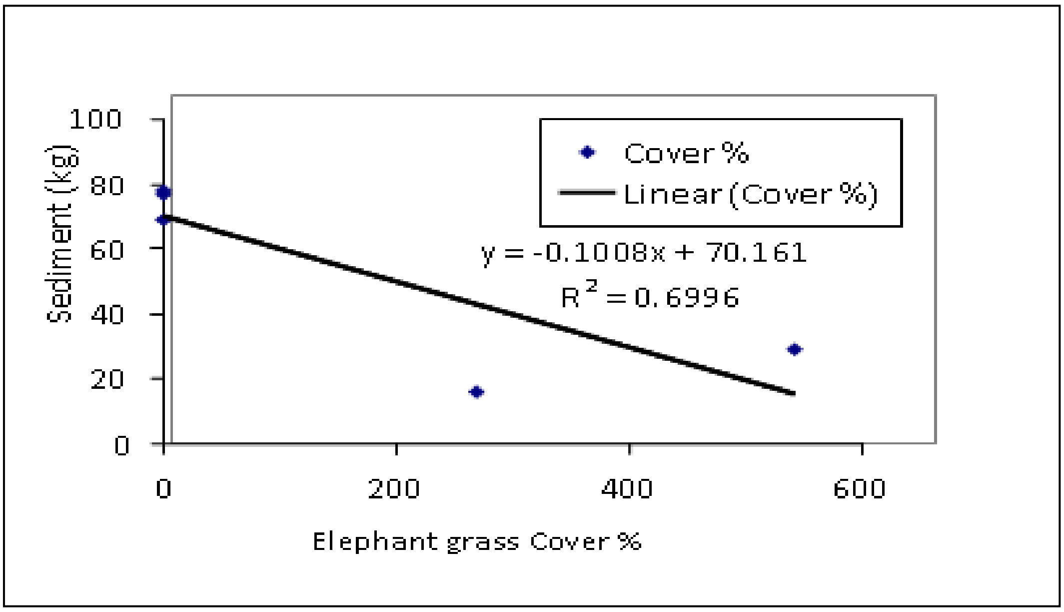

Figure 20a: Relationship between sediment delivery and cover percentage for elephant grass

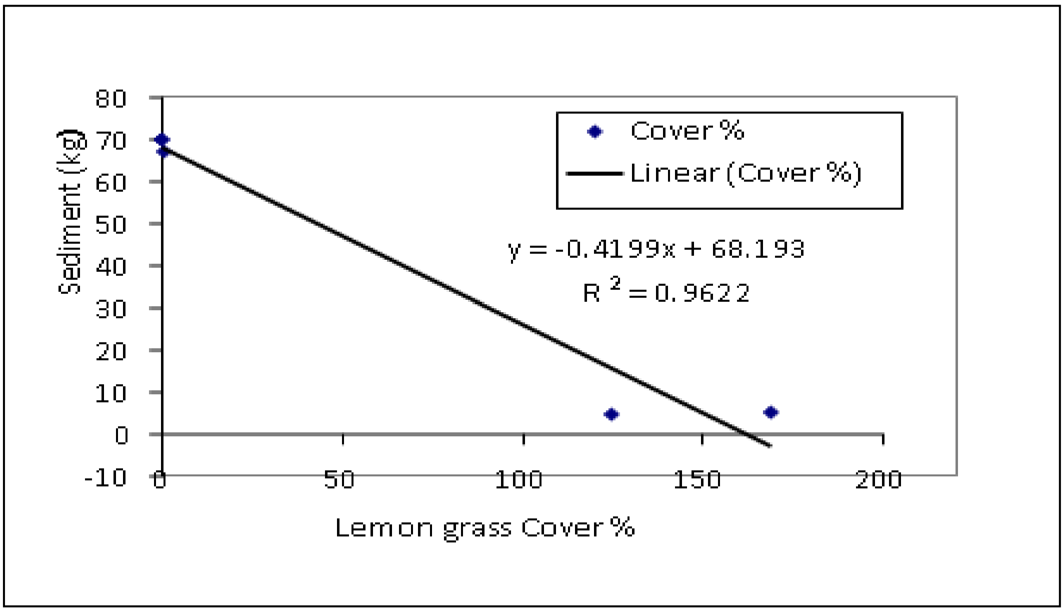

Figure 21b: Relationship between sediment delivery and cover percentage for lemon grass

Table 20: Relationship between runoff and sediment delivery and VBSFs growth characteristics and percent cover in Magu, Tanzania

VBSFs width (m)	**Runoff (m^3)**	**Sediment (kg)**	**Plant vigour (cm)**	**Percentage cover (%)**
0	0.040[a]	325.59[a]	7.08[b]	0.00[b]
2.5	0.028[b]	123.08[b]	47.70[a]	40.86[a]
5	0.021[c]	110.71[b]	44.05[a]	35.71[a]
10	0.014[d]	82.39[c]	46.81[a]	40.21[a]
Mean	0.03	160.44	36.41	29.20
$LSD_{0.05}$	0.004	24.67	11.43	7.64
Factor (b) Cover types				
Elephant(EG)	0.029[a]	185.43[a]	49.88[a]	32.41[a]
Lemon (LG)	0.023[b]	135.46[b]	22.94[b]	25.98[b]
Mean	0.03	160.44	36.41	29.20
$LSD_{0.05}$	0.003	17.45	8.08	5.40

Means with the same letter are not significantly different at 5%

4.3.3 Sediment-factor model to quantify the variability of sediment delivered from agricultural lands in the Lake Victoria shoreline

4.3.3.1 Sediment-factor regression model for elephant grass

Sediment-factor model for quantification of sediment delivery for elephant grass is presented in Table 21. According to the model, the rate of sediment delivery for elephant grass was significantly correlated with rainfall, strip width, vegetation growth/plant vigour and vegetation cover percentage. From this relationship, sediment delivery through elephant grass filter strip can be predicted as shown in equation (2) below:

$$Y = 238.18 + 2.83X_1 - 15.57X_2 - 0.14X_3 - \quad \ldots\ldots\ldots\ldots(2)$$

$1.33X_4$

Where Y = Sediment delivery (elephant grass)

X_1 = Rainfall

X_2 = Strip width

X_3 = Vegetation growth

X_4 = Vegetation cover percentage

Accordingly, sediment delivery through elephant grass filter strips decreases with increasing strip width, vegetation growth/plant vigour and vegetation cover percentage and increases with increasing rainfall. The model explained about 54% of the observed variation in the prediction of sediment delivery through elephant grass filter strip whereby the vegetation cover percentage alone explains about 33%.

Table 21: Multiple regression statistics for predicting sediment loss through elephant filter strips

Variable Entered	Parameter estimate	Partial R-Square	Model R-Square	F Value	Pr > F
Intercept	238.18				
Rainfall	2.83	0.0491	0.5369	25.04	<.0001
Width	- 15.57	0.1593	0.4878	73.71	<.0001
Growth	- 0.14	0.0014	0.5383	0.71	0.4007
Cover %	- 1.33	0.3285	0.3285	116.41	<.0001

These results agreed with the observations that sediment trapping efficiency of the vegetation filters is greatly increased with increase in vegetations strip widths (Gharabhaghi *et al*., 2001), growth/plant vigour (Dillaha *et al*., 1989), and Vegetation cover percentage (Smith, 1989) but significantly reduced with increasing amount of rainfall (Harden and Mathews, 2000).

4.3.3.2 Sediment-factor regression model for lemon grass

Sediment-factor model for quantification of sediment delivery for lemon grass is presented in Table 22. According to the model, the rate of sediment delivery for lemon grass was significantly correlated with rainfall, strip width, vegetation growth/plant vigour and vegetation cover percentage. From this relationship, sediment delivery through lemon grass filter strip can be predicted as shown in equation (3) below:

$$Y = 190.26 + 2.60X_1 - 16.35X_2 - 0.88X_3 - 0.89X_4 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3)$$

Where Y = Sediment delivery (lemon grass)

X_1 = Rainfall

X_2 = Strip width

X_3 = Vegetation growth

X_4 = Vegetation cover percentage

Accordingly, sediment delivery through lemon grass filter strips decreases with increasing strip width, vegetation growth/plant vigour and vegetation cover percentage and increases with increasing rainfall. The model explained about 41% of the observed variation in the prediction of sediment delivery through lemon grass filter strip whereby the vegetation cover percentage alone explains about 39%.

Table 22: Multiple regression statistics for predicting sediment loss through lemon filter strips

Variable Entered	Parameter estimate	Partial R-Square	Model R-Square	F Value	Pr > F
Intercept	190.26				
Rainfall	2.60	0.0142	0.4062	5.66	0.0181
Width	- 16.35	0.2934	0.2934	98.84	<.0001
Veg Growth	- 0.88	0.0260	0.4322	10.76	0.0012
Cover %	- 0.89	0.0985	0.3920	38.41	<.0001

These results agreed with the observations that sediment trapping efficiency of the vegetation filters is greatly increased with increase in vegetations strip widths (Gharabhaghi *et al*., 2001), growth/plant vigour (Dillaha *et al*., 1989), and Vegetation cover percentage (Smith, 1989) but significantly reduced with increasing amount of rainfall (Harden and Mathews, 2000).

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Pollution in terms of toxic chemicals, waste and sediment is a serious concern, in the Lake Victoria Basin. The magnitude of sediment pollution in Lake Victoria have been attributed to the alteration of riparian areas sometimes referred to riparian buffers zone areas through various land use changes and dynamics . The results from this study, shows that land use/cover in Magu District, Tanzania have changed drastically over the last 40 years. Settlement has increased three times while savannah associated with fallow areas has decreased by 50%. The observed land use dynamics and alteration of natural transition zone (riparian buffers) around Lake Victoria shoreline has rendered the protective nature of these areas ineffective and detrimental to the health of the lake water.

From this study it is revealed that mass of sediment delivered through the grass filter strips decreases exponentially with increasing Vegetative Buffer Strip Filter widths with correlation coefficient (R^2) ranging from = 0.6 to 0.8 . The results also show that, mean difference for Vegetative Buffer Strip Filter width and vegetation types is highly significant ($P \leq 0.05$). Also zero metre is significantly different from 2.5, 5, and 10 metre.

These observations demonstrate that the amount of sediment trapped by Vegetative Buffer Strip Filters and their corresponding widths are significant up to a width of 10 metres. However, the potential for the buffer to become clogged with fine sediment over time can undermine the effectiveness of the Vegetative Buffer Strip Filters.

The results demonstrate further that Vegetative Buffer Strip Filters (VBSFs) like the lemon and elephant grass can become effective filters in removing sediment inputs to surface waters of Lake Victoria by restricting a minimum land area not exceeding 10 m under the tested VBSFs. The tested VBSFs have the potential to purify water that has been transported into the riparian zone from the agricultural lands.

Results from this study, indicate that the effectiveness of VBSFs to trap sediment from agricultural fields is a function of vegetation and site characteristics.

5.2 Recommendations

Buffer strips are likely to be clogged with fine sediment over time which can undermine their effectiveness in trapping sediments. Therefore, it is recommended that a study on optimum buffer widths should be conducted to take into account the vegetation recovery rate after clogging.

This study focused on sediment transported by overland flow. There is a need to assess the contribution of concentrated flow at much wider scale to the overall sediment delivery into Lake Victoria riparian buffer zone. Results from this research will provide an opportunity for developing user friendly decision support aid (DSSA) for designing VBSFs for management of sediment pollution in the Lake Victoria riparian zone. Prior to this and given the varied Lake Victoria Ecosystem, there is need to conduct VBSF research in different key ecological settings in the Lake Victoria riparian zones including areas of convergent concentrated flow.

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APPENDICES

Appendix 1: The Analysis of Variance (ANOVA) Table for vegetation filters test and strips width

Variable	Source	df	SS	MS	F	P	Level of significant
Runoff	Rep	3	0.000069	0.000023	0.12	0.95	ns
	Level	3	0.042	0.014	74.41	<.0001	***
	Rep*Level	9	0.0009	0.0001	0.46	0.90	ns
	Treat	1	0.0046	0.0046	24.12	<.0001	***
	Level*Treat	3	0.00138	0.00046	2.42	0.07	ns
	Error	460	0.088	0.00019			
	Total	479	0.138				
	CV (%)						53.64
	R-Square						0.36
Sediment	Rep	3	5794.56	1931.52	0.20	0.89	ns
	Level	3	4468245	1489415	157.42	<.0001	***
	Rep*Level	9	23352.12	2594.68	0.27	0.98	ns
	Treat	1	299550.17	299550	31.66	<.0001	***
	Level*Treat	3	76150.47	25383.49	2.68	0.05	*
	Error	460	4352152	9461.20			
	Total	479	9225244				
	CV (%)						60.62
	R-Square						0.53
Slope	Rep	3	31.50	10.50	82.99	<.0001	***
	Level	3	0.00	0.00	0.00	1.0000	ns
	Rep*Level	9	0.000.00	0.00	0.00	1.0000	ns
	Treat	1	19.20	19.20	151.75	<.0001	***
	Level*Treat	3	0.00	0.00	0.00	1.0000	ns
	Error	460	58.20	0.13			
	Total	479	108.90				
	CV (%)						0.47
	R-Square						0.47
Growth	Rep	3	1361.04	453.68	0.22	0.88	ns
	Level	3	138502.86	46167.62	22.73	<.0001	***
	Rep*Level	9	1819.44	202.16	0.10	0.9996	ns
	Treat	1	87132.32	87132.32	42.90	<.0001	***
	Level*Treat	3	31690.41	10563.47	5.20	0.0015	**
	Error	460	934187	2030.842			
	Total	479	1194693				
	CV (%)						123.77
	R-Square						0.22
Cover	Rep	3	454.65	151.55	0.17	0.92	ns
	Level	3	138272.1	46090.7	50.85	<.0001	***
	Rep*Level	9	3801.33	422.37	0.47	0.90	ns
	Treat	1	4952.33	4952.33	5.46	0.02	*
	Level*Treat	3	2059.44	686.48	0.76	0.52	ns
	Error	460	416953.79	906.42			
	Total	479	566493.63				
	CV (%)						103.12
	R-Square						0.26

ns = not significant

*** = highly significant different (P<0.001)

Appendix 2: Experimental layout to determine the effectiveness of selected vegetation and its strips width as sediment filters