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INFLUENCE OF HUMAN ACTIVITIES ON LAND USE CHANGES AND ENVIRONMENTAL QUALITY OF RIPARIAN ECOSYSTEMS: "A CASE STUDY OF SAIWA SWAMP WATERSHED, WESTERN KENYA"

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DECLARATION

I, William S. Ruto, do hereby declare that this thesis is my original work and has not been presented for a degree in any other university. No part of this research should be reproduced without my consent or that of the University of Nairobi.

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ACRONYMS AND ABBREVIATIONS

°C – degrees Celcius

AAS - atomic absorption spetrophotomer

ANOVA – analysis of variance

ASAL – arid and semi-arid lands

asl – above sea level

ASTER - Advanced Spaceborne Thermal Emission and Reflection Radiometer

Ca - Calcium

CART - Classification and Regression Trees

Cu - Copper

EMCA - Environmental Management and Coordination Act

ETM+ - Enhanced Thematic Mapper Plus

FAO – Food and Agriculture Organization (of the United Nations Organizations)

Fe - iron

GDEM - Global Digital Elevation Model

GoK – Government of Kenya

ha – hectares

K - Potassium

KARLO - Kenya Agricultural & Livestock Research Organization

Km -kilometre

KSS - Kenya Soil Survey

L1T - level 1 terrain

LBDA - Lake Basin Development Authority

LSD - Least Significant Difference

LULC - land use-land cover

Mg - magnesium

mg/Kg – milligram/kilogramme

mg/L – milligram/ litre

Mn - manganese

Nm - nanometer

OLI - Landsat 8 Operational Land Imager

OOB - out-of-bag

PA - producer's accuracy

Ppm – parts per million

RF - Random Forest

SSNP – Saiwa Swamp National Park

TM - Landsat Thematic Mapper

UA - user accuracy (or CA – consumer accuracy)

USGS - United States Geological Survey

UV – ultra violet

WWF - World Wide Fund for Nature

Zn - zinc

ABSTRACT

This study focused on the Saiwa Swamp watershed in western Kenya an area with mixed farming systems. The watershed is drained by Saiwa and Sitatunga rivers that feed the River Nzoia system that flows into Lake Victoria. The watershed is the main water catchment of one of the smallest conservation areas, the Saiwa Swamp National Park (3 km^2). Saiwa Swamp National Park is conservation area and habitat to the rare and endangered sitatunga antelope (*Tragelaphus spekei*). As the Swamp is surrounded by farms, making it an ecological island, this threatens the very existence of this important wetland and the conservation of the sitatunga antelope. It was postulated that increase in human population and related human activities would have profound impacts on the watershed and eventually would affect Saiwa Swamp. The study, therefore, looked at the population dynamics, soils and the land use and land cover changes in the watershed. By understanding the various human activities in the watershed this would provide the pre-requisite knowledge on how to mitigate negative impacts on of the Saiwa Swamp. The study also compared the chemistry of surface water and soil sediments at specific sites along the Saiwa Swamp gradient during the dry and rainy seasons. Results from the study show significant land use and land cover changes (LULC) have taken place in the watershed in the last 3 decades since 1985. Although built-up and riparian areas covered about 0.46% and 0.81% of the watershed, these two land use types showed significant increase and a decline respectively. The LULC changes were largely attributed to socio-economic drivers including population increase and extensive agriculture. There is hence need to strengthen law enforcement on physical planning in order to reduce encroachment of natural areas such as forests and riparian zones. The study also recommends further assessment and monitoring of spatial and temporal based land use and land cover changes in Kenya. pH of surface waters was nearly neutral (mean of 7.0) during the entire study period while that of the soil sediments was acidic (4.6 to 5.0). Elements Ca, Mg and Fe recorded higher concentrations in dry season compared to the wet season. Other elements including Cu, Mn and Zn were not detected in surface water during the dry season. There was an increase in concentrations of Cu and Mn in the Swamp waters during the wet season. It appears that agrochemicals released from the surrounding farms are channelled into the Swamp thus affecting its physico-chemical status. The findings of the study showed a high percentage of the nutrients were removed from the subsurface water by plants and soils and this further emphasises their role in filtering contaminants from runoff waters. This demonstrates the vital role of wetlands in pollution control and the need to maintain and restore wetland vegetation along riparian zones. In general, this study found that swamps played this vital role of retention of chemicals and metal elements, especially during the dry season when water flow is low and slow, and has longer residence times within the swamp to allow for filtration and mopping up of these chemicals and sediments.

CHAPTER 1: INTRODUCTION

1.1 Introduction

This Chapter introduces, the rationale of the study and the issues to be addressed in this study. The Chapter also attempted to determine the justification of the study based on gaps in knowledge in this study area and research topic. The findings of the study will enhance scientific knowledge in the research area.

1.2 Study Background

According to the report by United Nations (2017) Kenya's population had doubled to about 40 million people by 2009, and this rapid population growth is set to continue in the foreseeable future. Based on these projections, population of Kenya is set to grow by around 1 million per year over the next 40 years reaching about 85 million by 2050. Although agriculture remains the mainstay of the economy, Kenya is set to undergo steady industrial transformation in line with Vision 2030 (GoK 2007). With an estimated area of about 587,900 km^2, Kenya has a surface area of 576,000 km^2. Majority (88%) of this land surface is classified as arid and semi-arid lands (ASAL) and the remaining 12% forms the medium and high agricultural potential land where most of agriculture is practiced. Part of the 12% of the high potential agricultural land are the wetlands which are critical ecosystems that provide vital ecosystem good and services (GoK, 2006).

According to the Ramsar Convention (Ramsar, 2013) wetlands are those "areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water the depth of which at low tide does not exceed six metres". Wetlands are fed by systems originating from their particular watersheds. These human activities can have profound impacts on ecosystems in these watersheds especially wetlands (Mitsch and Gosselink, 2007). Direct and indirect watershed changes can be linked to human activities. Wetlands are habitats that mostly support aquatic plants and are important by trapping sediments, and retaining excess nutrients and pollutants such as heavy metals modulate water quality (Mitsch and Gosselink, 2007).

Wetlands are unique environments that have soils either permanently or seasonally saturated with moisture and have their water tables that stand near or at the land surface. Wetlands offer important ecosystem services through their ecological functions. The ecosystem functions of wetlands (such as trapping sediments, retaining excess nutrients and pollutants such as heavy metals resulting in modulation of water quality) are especially important where a wetland is connected to rivers and lakes, whose waters are utilised by humans and livestock. Where wetlands occur in developing countries, they are under heavy and increased pressure from their conversion into agricultural, fish ponds and urban development projects thereby diminishing their vital ecosystem functions (Mitsch and Gosselink, 2007).

Saiwa Swamp is part of the Saiwa watershed ecosystem located west Kenya, hosts important plant and animal species, remarkable among them being the endemic antelope sitatunga *Tragelaphus spekei* and crowned cranes *Balearica regulorum* (Mohamed, 2000). Human activities in the Saiwa watershed, including farming and deforestation, definitely influence ecosystems functions. In the early 1960s, people migrated from other parts of Kenya to this rich agricultural area to benefit from the aftermath of colonial resettlements (Shaffer, 1967). This resettlement resulted into rapid growth in human population leading to substantial sub-division of the land in the Saiwa watershed. Moreover, to increase agricultural production, most of the farmers practice use agro-chemicals whose residues are carried in runoff into the wetlands leading to untold ecological changes (Kithiia, 2006). Therefore, these intensive agricultural activities not only threaten the Saiwa wetland and its biodiversity but also its greater watershed.

1.3 Rationale and Justification for the Study

Deforestation and vegetation clearing are human induced land use changes in many tropical countries including Kenya. Deforestation occurs due to many factors including illegal logging, poor soils that require more and more land to raise foodstuff and cattle rearing in order to feed the ever increasing human populations, more land for urban development, mining and setting up of industries (WWF, 2017).

It is postulated that more than half of the wetlands in the world may have disappeared through conversions to other land uses since the beginning of the 20th Century (Barbier, 1993 and 1994). While most of this wetland loss has occurred in developed countries, the loss is on the rise in the developing world, and more so in the tropics due to increases in human populations. In African countries, especially Kenya, most of these wetland conversions were for land for agricultural purposes, for fishponds, and for urban settlements (Farber and Constanza, 1987; Mohamed, 2000).

Saiwa Swamp, one of the most critical wetlands in Kenya is situated in a watershed that is experiencing increasing human population pressure especially due to farming activities (mainly through cultivation of maize which is the staple food crop for most Kenyans) (Mohamed, 2000).

The Saiwa watershed, located about 400 km west of Nairobi, is home to a small population of endangered and endemic semiaquatic Sitatunga antelope (*Tragelaphalus spekei*). This population is threatened by agricultural practices that are often intensive, and if not checked, may result in severe ecological impacts and damage.

1.4 Statement of the Problem

Kenya has very few wetlands available due to encroachment by agricultural and other human activities (Abila *et al*., 2008). These agricultural activities have led to increased levels of sedimentation and pollution of major water bodies due to the reduction in wetlands as buffer zones (Abila *et al*., 2008). For example, in a few studies carried out in swamps such as the Yala Swamp have shown that human activities, including farming, deforestation and expansion of urban areas, greatly affect the status of these wetlands (Abila *et al.*, 2008; Kairu, 2001; Kithiia, 2006, Mohamed, 2000). However, only a few studies (Abila *et al.*, 2008; Kairu, 2001) have been carried out in Kenya on how these type of activities taking place within a watershed affect the adjacent wetlands.

1.5 Significance of the Study

Land-use practices vary greatly across the world. However, their ultimate outcome is generally the same: altering the structure and functioning of ecosystems and how these ecosystems interact with surrounding lands, the atmosphere, and with aquatic systems. Quantifying land transformation is essential in understanding the complex interactions and impacts between the natural and human environments at local, regional, and global scale.

For the Saiwa Swamp watershed ecosystem, Landsat archive satellite imageries, freely available from the United States Geological Survey (USGS) were used to address this gap and to gain an in-depth understanding of the magnitude and trends in land use and land cover changes. The study explored land cover changes in the Saiwa watershed over the past three decades (1985 - 2015). The aim was to map and elucidate the changes in the main land use and land cover types within the Saiwa Swamp National Park watershed.

In addition, the study aimed at investigating the ecological impacts (including status of various nutrients in water and soil sediments) and impacts of human activities on the Saiwa watershed ecosystem, in Kenya. The study further assessed and, compiled a checklist of the plant species present within the Saiwa swamp. Therefore this study will give great insights on the status of the Saiwa watershed and the swamp in particular and elucidate in detail what changes may have been taking place over the last few decades, thereby affecting the ecosystem as a whole.

1.6 Objectives of the Study

The general objective of this study was to map out the impacts of human activities within the Saiwa watershed over the last few decades and their effects on the riparian ecosystem.

1.6.1 Specific objectives

The specific objectives of the study were:

1. To determine role of human activities on land use and land cover changes in the Saiwa watershed over the last three decades since 1985,

2. To explore the linkages between human activities and the ecological status of the Saiwa Swamp by gauging the seasonal mineral status of water and soil sediments, and
3. To compile a plant species checklist of the Saiwa swamp National Park.

1.7 Hypotheses

Hypothesis 1: Increase in human population and human activities have led to changes in land use and land cover within the Saiwa watershed.

Hypothesis 2: Human activities have impacts on the ecological status of the Saiwa swamp by influencing the amount of mineral nutrients in water and soil sediments.

Hypothesis 3: Saiwa swamp is composed of varied plant species.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This Chapter attempts a review of the literature on land use and land cover changes, and on issues of water and soil sediments quality in wetlands relevant to the current study and with particular relevance to the Kenyan situation. It attempts to review the current literature status on the research topic with an aim that the findings of this study would add to better scientific knowledge on land use and land cover changes and their impacts on water and soil sediments quality of the wetlands.

2.2 History of land use in Kenya

According to Cone and Lipscomb (1972), the history of land transformation in Kenya can be divided into three major periods: and these are the pre-colonial, colonial and post-independence periods. In pre-colonial times, a combination of pastoralism and subsistence agriculture was the major type of land use. Agriculture was basically at the subsistence level based on shifting cultivation; and since the human population density was low, fallow periods were long and regular. Agricultural cropping included growing of bananas, yams, sweet potatoes, millet, sugar cane, tobacco and a little cassava. With the influx of white settlers into the so called "White Highlands" (an area in the central uplands of Kenya) during colonial period in the early years of the 19th century, agriculture became more extensive resulting into both a direct and indirect impacts on the tree cover. During the post-independence period, many colonial white settlers left and their large farms were earmarked for resettling in smaller land units the many landless native population (Cone and Lipscomb, 1972). This led to intensive small scale farming practices and clearing of much of the indigenous vegetation, including forests and wetlands (Bilsborrow and Okoth-Ogendo, 1992).

2.3 Land use and land cover changes

By clearing of natural vegetation cover, intensifying cropland production and expanding urban areas, anthropogenic activities are changing the world's landscapes in many profound ways (Foley *et al.*, 2005). Many land-use practices, although vary greatly across the world, result generally in the same ultimate outcomes: altering the structure and functioning of ecosystems; and how these ecosystems interact with surrounding land, with aquatic systems and with the atmosphere. We earlier noted that large proportion of the planet's land surface have been altered profoundly by changes in land use activities (DeFries *et al.*, 2007). Due to the significance of these changes on the biosphere that result in alteration of ecosystems, monitoring changes in land cover is one of the high priority areas for research (DeFries *et al.*, 2007). Quantifying land transformation is essential if we have to understand the complex interactions and impacts between the natural and human environments, from local, regional to global scales. This can be done by using multi-temporal analyses of land use and land cover that provide important insights into long term trends and which serve to identify drivers and determinants of these changes (DeFries *et al.*, 2007).

It was noted above that the history of land transformation in Kenya can be divided into three major periods: and these are the pre-colonial, colonial and post-independence periods (Cone and Lipscomb, 1972). In pre-colonial times, a combination of pastoralism and subsistence agriculture was the major type of land use. Agriculture was basically at the subsistence level based on shifting cultivation; and since the human population density was low, fallow periods were long and regular.

Agricultural expansion presents some of the most significant changes in land use. These result in declines in areas covered by natural vegetation formations such as forests, bush land, grasslands and wetlands (Githui *et al.*, 2009). These changes are basically driven by increases in human population that fuels more demand for food and fuel wood. Although in the past these significant changes in land use and land cover have allowed sustained human population growth and economic development, it now raises concerns regarding local, regional and global environmental impacts and their consequences on human well-being especially in this age of climate change.

One of the major challenges of today's society is to reconciling trade-offs between food security, economic growth and ecosystem services (Godfray *et al.*, 2010). In order to formulate sustainable development goals, improved understanding of local, regional, to global land use changes and their negative environmental impacts is required. For interpreting the complex ecosystem status due to changes in land use-land cover, the most important aspects of this exercise is the timely acquisition of relevant information on land use and land cover changes (Turner *et al.*, 2007). One of invaluable sources is the medium spatial resolution data on long term land cover monitoring from the Landsat satellite image archives (that currently store more than four decades of multispectral observations across the planet).

2.4 Wetlands

As discussed in Section 1.2, more than half of the wetlands in the world may have disappeared through conversions to other land uses since the beginning of the 20th Century (Barbier, 1993 and 1994). While most of this wetland loss has occurred in developed countries, the loss is on the rise in the developing world, and more so in the tropics due to increases in human populations. In African countries, especially Kenya, most of these wetland conversions were for agricultural purposes, for fishponds, and for urban settlements (Farber and Constanza, 1987; Mohamed, 2000). In Kenya, this has been documented in central Kenya, western Kenya and in the Rift Valley areas (Kairu, 2001).

In Kenya, this is due to the rapid human population growth, increased levels of industrialization and urbanization, which largely contribute to loss and unsustainable use of wetlands (Abila *et al.*, 2005). This has led to the disappearance and serious degradation of many of Kenya's wetlands (Mironga, 2005a, 2005b) especially those surrounded by areas of high human populations and intensive agricultural activities (Abila *et al.*, 2005). This may have led to disappearance and reduction of important wetland habitats leading to subsequent loss of many useful plants and animals that are dependent on these wetlands. Therefore, the major threats facing the conservation of wetlands in Kenya are human encroachment and settlement (Chapman *et al.*, 2001).

2.5 Ecosystem disturbances and species diversity

Ecological disturbance frequencies, intensities, scale and timing are major factors that determine the rate of ecosystem degradation (Hobbs and Huenneke, 1992). Ecosystem disturbances are caused by natural and anthropogenic factors including fires, herbivory, floods, drought, diseases, nutrients inputs and soil trampling among others (Tracey *et al.*, 2007). The response of any given plant community to ecological disturbance is determined by the type of the species found therein (Cartford *et al.*, 2012). Many ecosystems have been known to maintain their highest species composition at moderate perturbations (Hobbs and Huenneke, 1992) as many species tend to gradually and continually change in order to adapt to these perturbations (Petraitis *et al.*, 1989). Plant communities with many different species are considered to be more diverse and most tend to be within the tropical regions (Brown, 2014). Ecological diversity indices provide ecological information that is important in understanding community structure, composition and function (Lulekal *et al.*, 2008). According to Myers *et al.* (2000), distinct geographic patterns of species diversity have played important role in prioritizing and initiating conservation measures in various ecosystem.

2.6 Plant species composition and diversity

The complexity in the physical, chemical and human environment (including habitat disturbances) determines in a great extent the diversity of plant species within a plant community (Sundt-Hansen *et al.*, 2006; Whittaker, 2006; Moss, 2008). It has been clearly shown that there is a strong coupling effect between anthropogenic disturbances and environmental quality in catchment areas and their surrounding ecosystems where what happens in one area of the catchment affects other areas within and outside that particular catchment. This was demonstrated in the case of Saiwa swamp ecosystem by Gichuki *et al.* (2001). Studies by Abila *et al.* (2008) and Allen *et al.* (2005) have demonstrated that human activities including clearing wetlands for cultivation have a very fundamental influence on plant species composition of many wetland environments. Burns and Schallenberg (2001) also showed that human activities including agriculture, fire and livestock grazing in wetlands lower species diversity. By clearing land for cultivation, settlements or draining of wetlands, human activities degrade the natural habitats and this may lead to local disappearance or extinction of some local species, and therefore reducing species diversity (Primack, 1993) and water quality of the affected wetlands (Abila *et al.*, 2008).

2.7 Ecological functions of wetland vegetation

One of the most important roles of wetland vegetation is acting as a buffer zone between terrestrial activities and aquatic ecosystems (Newham *et al.*, 2005). This buffering role of wetland vegetation includes filtering particles from anthropogenic sources after their subsequent translocation into river ecosystems through overland flow or runoff and through wind transport (Newham *et al.*, 2005). When wetland vegetation is removed or cleared, larger volumes of particulate matter and soil sediment may be delivered into adjacent water body. This increase in sediment volumes can choke aquatic habitats while the increased nutrient (bound to the surface of soil sediment particles) will stimulate weed and algal growth causing eutrophication of the water body (Newham *et al.*, 2005).

In many watersheds, wetlands buffers are commonly used as a regulatory tool to moderate many human impacts from land use. The presences of wetland vegetation buffer can positively influence the water quality of a stream or water body by lowering the water temperature and the loading of nutrients and sediment onto the water body (Divya and Belagali, 2012). In addition, wetland buffer may influence the hydrology of a water body by interception of rainfall, and storage of overland runoff thereby reducing floods. Water purification, flood protection, shoreline stabilization, groundwater recharge, and stream flow maintenance and providing habitat for fish and wildlife, including endangered species are other environmental benefits of wetlands (Divya and Belagali, 2012).

The range of naturally occurring functions that benefit to human societies are classified as ecosystem goods and services (Lovett *et al.,* 2004). These ecosystem goods and services include carbon storage, water filtration and salinity control, a habitat for pollinating insects, providing grazing and shelter for livestock, and provision of wood products (e.g. timber, poles, charcoal), seeds, essential oils, foliage, honey, bush foods and pharmaceuticals (Lovett *et al.,* 2004).

Removal of wetland vegetation has the capacity to lower the ability for these ecosystems to provide these services, resulting into an increase of costs related to substitution of the services, loss in production or increased costs of resources refinement, e.g. water purification for domestic uses. Due to the importance of wetland vegetation in the landscape, and the ecosystem goods and services they provide and also in respect to the threats facing wetland vegetation, native wetland are clearly recognised in law in Kenya and should therefore be a major research target.

2.8 Water Quality

As an environmental buffer, wetlands vegetation moderates three particularly important components of water quality: these are temperature, nutrient levels and sediment loads. As noted elsewhere in this review, the vegetation in the wetland shades the stream and decreases water body temperature (Karr and Schlosser, 1977). The vegetation also decreases evaporation and convection in the near stream area as a result of which a microclimate which moderates the stream temperature by preventing extremely low or high temperatures is created (Karr and Schlosser, 1977). This reduces the daily and seasonal fluctuations in stream temperature (Karr and Schlosser, 1977).

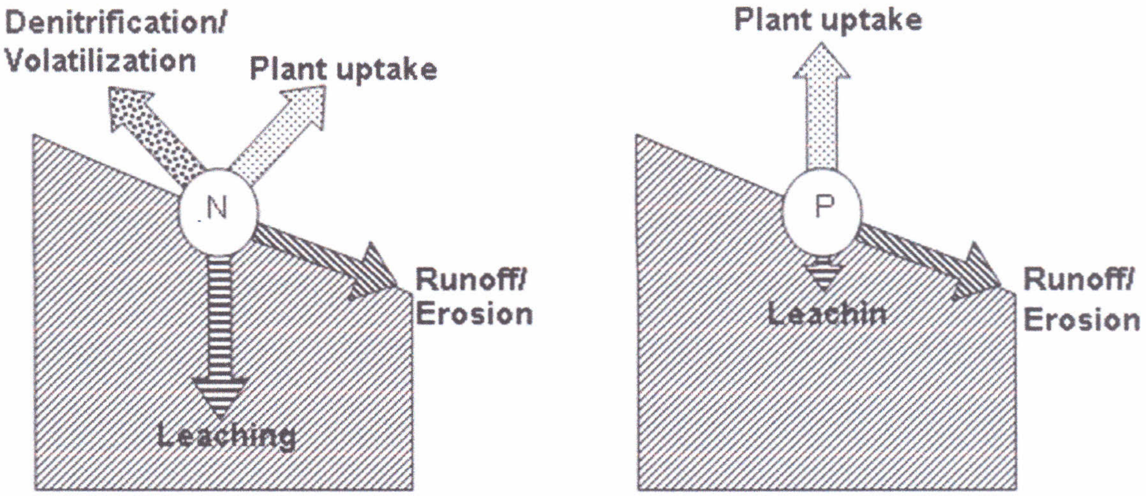
The availability and cycling of nutrients within a riparian environment is very important in the functioning of the ecosystems (Raburu, 2003; Kithiia, 2006). Analysis of the changes in riparian water quality often reveals the impact of different activities taking place within a river basin or watershed. The vegetation present in the wetland buffer is also a key component of the nutrient cycle through various ways. This wetland vegetation absorbs and by so doing filters high levels of dissolved nutrients (Gregory *et al.*, 1991). Vegetated wetland buffers have been shown to remove between 65% to 100% of the nitrogen and 30% of the phosphorus from the surface and ground waters in some wetland ecosystems (Lowrance *et al.*, 1984; Osbourne and Kovacic, 1993). Through the process of denitrification, nitrogen is removed by the wetland buffer especially under anoxic conditions (Triska *et al.*, 1993). By removing the dissolved nutrients which could be detrimental to stream biota or lead to eutrophication of the water body, this function directly affects the stream condition positively by making the water of a better quality.

Removing the source of leaves, twigs, fruit and insects that form the basis of in-stream food webs changes the quantity and quality of energy in food webs and the functioning of the ecosystem. This effect could have far reaching consequential impacts on in-stream faunal and floral population abundance and biodiversity.

2.9 Mineral nutrients

Studies on the chemical composition of waters have been done on various wetlands in Kenya, primarily on Lake Naivasha (Gaudet, 1979; Muthuri *et al.*, 1989; Harper *et al.*, 1999) Yala swamp (Abila *et al.*, 2008) Saiwa and Nyando swamps (Raburu, 2003; Abila *et al.*, 2005; Owino and Ryan, 2007; Obiero, 2008). Most of these studies have revealed that the chemical composition of the water vary depending on their location in the wetlands (Muthuri and Jones, 1997), geology (Masese *et al.*, 2008; Okoth *et al.*, 2009), and human impacts on the catchments (Raburu, 2003). These changes in chemical status of water have corresponding impacts on the aquatic biota of the ecosystems, for example proliferation of aquatic weeds (Gaudet, 1979; Muthuri *et al.*, 1989; Harper *et al.*, 1999).

Mineral nutrients are an important chemical factor in wetland ecosystems (Hutchinson, 1975; Moss, 1980; Goldman and Horn, 1983; Burgis and Morris, 1987; Haven *et al.*, 2001; McCartney *et al.*, 2005). The most important nutrients are those that are often short in supply and limit growth of plants (Almazan and Boyd, 1978; Downing, 1999). Both nitrogen and phosphorus are essential to life processes (Reynolds, 1984) but while there are many sources of nitrogen, phosphorus is often in short supply and therefore limiting to plant growth (Hecky and Kilham, 1973; Moss, 1980; Goldman and Horn, 1983; Burgis and Morris, 1987) due to its loss from the system primarily through runoff (Figure 2.1).



Nitrogen

Phosphorous

Figure 2.1: Simplified depiction of the mechanisms of N and P loss from agricultural fields. (Credit: Dr. A.L. Shober. Department of Plant and Soil Sciences, University of Delaware, Newark, USA).

2.10 Legal position on wetland vegetation

Buffering of streams is required by law; however, this remains unregulated on most farmlands. Under the Kenyan laws, rivers are public resources and accessible to anybody at any time. The Government Lands Act, Cap 280, states that the wetland (riparian) zone, including the vegetation which grows along the river, is government property. This is also covered under the Water Act 2016, the Forest Conservation and Management Act, 2016, the Lakes and Rivers Act, Cap 409, and the Agriculture Act, Cap 318. By law the two pieces of land on both sides of the river, referred to as the wetland zone, are to be left intact. However, in most cases due to the enormity of the task of definition and enforcement, management of the wetland zone is left to the interpretation of the individuals owning land adjacent to the river or water body. In practice, this leads to many land owners clearing the vegetation and using the land right up to the edge of the river.

Under the Constitution of Kenya 2010, the State has powers to regulate the use of private land or entirely abrogate property rights in the same land in the national interests of environmental conservation. This position therefore explains the importance of land tenure in resource use and conservation in Kenya. The issue of resource tenure systems arise because natural resources are scarce and must be distributed equitably among all users or claimants where they occur. Any use of agricultural land in Kenya is regulated by the Agriculture Act, Cap 318 which seeks to secure the proper utilization and management of agricultural land in order to maximize output. The main environmental law in Kenya, the Environmental Management and Coordination Act (EMCA) of 1999 (Amended 2015) (Republic Kenya, 2015), clearly recognises this position.

In Kenya, therefore, the National Land Policy (GoK, 2009) and the Environmental Management and Coordination Act (EMCA) of 1999 (Amended 2015), have well defined legal frameworks including legal statutes that complement sectoral statutes on water, health, forestry, agriculture and industry. On the whole, the National Land Policy and EMCA do not intend to repeal the aforesaid sectoral legislations, but instead they seek to coordinate the activities of the various agencies tasked in the regulation of these various sectors.

CHAPTER 3: GENERAL STUDY AREA, MATERIALS AND METHODS

3.1 Introduction

The chapter describes the study area and its general characteristics including climate, topography and geology, soils, flora and fauna of the watershed. It also includes the farming activities *and* human population dynamics within the watershed. The chapter also provides detailed information on the research design, materials and methods used to obtain data on population dynamics, watershed soil map delineation and the mapping of land use and land cover changes within the Saiwa watershed. It also describes the sampling methods and chemical analyses for water and soil sediments.

3.2 Description of the Study Area

The Saiwa wetlands are located within the Saiwa watershed. This watershed is located mostly within in the Trans-Nzoia County, with some small areas located in West Pokot and Elgeyo Marakwet counties in the western part of Kenya. Part of these wetlands form one of the smallest parks in Kenya, the Saiwa Swamp National Park (SSNP) which has an area of 2.9 km^2 (Mohamed, 2000). The Park is situated in Sinyerere ward 25 km north-east of Kitale town (01° 05' N, 35° 07' E), at an elevation of about 1860m asl (Figure 3.1). The Park is located at the confluence of rivers Saiwa (which originates from the Cherengany Ranges at 3371m asl to the north) and Kipsaina (which originates from Mt. Elgon 4321m asl to the west). The two rivers join to form river Sinyerere that flows into River Nzoia further downstream and that drains its waters into Lake Victoria (Kavishe, 2001). The watershed boundaries were derived from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) version 2 with 30m spatial resolution that delineated an area of about 27,500 hectares.

The Saiwa wetlands are host to important biodiversity, but are threatened by intensive agriculture carried out within the catchment area. Threats include encroachment of the wetlands by neighbouring farmers and by agricultural chemicals transported by runoff from the adjoining farms. These may have major negative impacts on the biodiversity of this ecosystem.

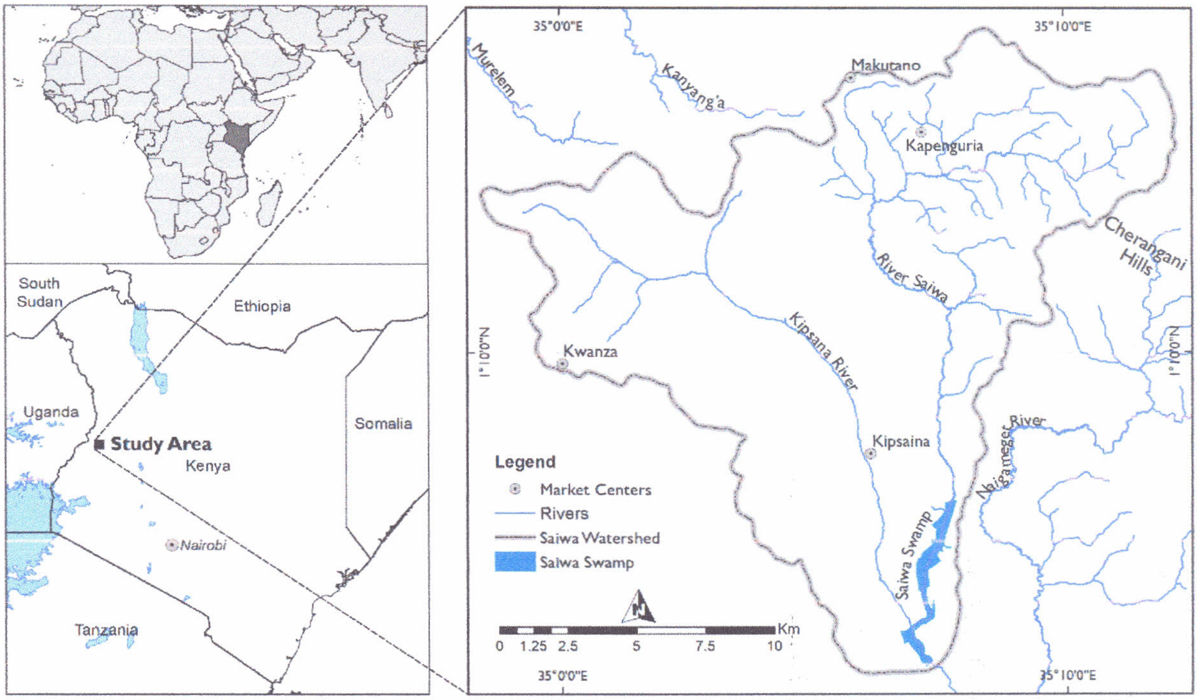


Figure 3.1: Location of the Saiwa Swamp Watershed

3.2.1 Climate

The study area is located in agroecological zone III (Jaetzold and Schmidt, 1983). Long-term rainfall records show that during the period from 1950 - 2000, the mean annual precipitation of the watershed was about 1080 mm and a mean annual temperature of about 17.2 °C (Hijmans *et al.*, 2005). Most of this precipitation falls between March and November with May being the wettest month of the year, while the driest months are December, January, and February. Mean daily minimum and maximum temperatures over the same period are 9.3 °C and 16.1 °C in July and 22.9 °C and 26.7 °C in February (Hijmans *et al.*, 2005).

3.2.2 Topography of the Watershed

The general topography of the Saiwa watershed ranges from the undulating Uasin Gishu Plateau on the western side, with altitude mainly between 1850 and1970m asl, to foot hills and mountain slopes of Cherangany system with altitude between 1970 and 2368 m above sea level. Topography around the park varies from completely flat to very steeps slopes in some few areas (Kavishe, 2001).

3.2.3 Geology of the Watershed

The Saiwa watershed is underlain by rocks of the Precambrian basement system covered by a layer of tertiary sediments resulting from volcanic activity of Mt. Elgon (Kavishe, 2001). A hard crust was formed in the soil profile from sediments and sands resulting from eruptions of the Cherengany Ranges. As a result, the crust forms a high water table below the surface (Mohamed, 2000). These rocks of the Precambrian basement system consist mainly of quartzites and schists derived from argillaceous and arenaceous sediments which have been transformed by metamorphism and recrystallization into quartz and feldspar-rich rocks with much muscovite, biotite, and hornblende minerals (Miller, 1956).

3.2.4 Soils of the Watershed

The Saiwa watershed is generally characterized by soils that differ strongly in depth, chemical fertility, organic matter content and physical behaviour (Gelens *et al.*, 1976). The plateau area of the watershed has mainly deep soils (Ferralsols) while undulating northern part have deep to shallow soils which in general liable to sheet erosion (Acrisols). The minor valleys and flat valley bottom have association of soils ranging from peat and very poorly drained, deep, mottled clay (Histosols and Gleysols).

3.2.5 Flora and fauna of the Watershed

The general land cover of Saiwa watershed consists of remnant *Combretum* wooded grasslands surrounded by agro-forestry parklands and cultivated lands on the plains (Kavishe, 2001). Mountain slopes and foot hills are dominated by *Aningeria-Strombosia-Drypetes* forest. Evergreen clump-grassland occurs on viel soils in minor valleys and bottomlands mainly on Saiwa and Sitatunga rivers. The marshland, that occur in these viel soils, consists of large stands of bullrush (*Typha domingensis*), reeds (*Cyperus latifolia*) and tall swamp grasses such as *Echinochloa pyramidalis*.

The Saiwa National Park contains some of the original indigenous vegetation types of the area most of which have now been cleared for cultivation and settlements. Common plant species include *Prunus africana, Croton macrostachyus* and *Albizia gummifera* (Ogutu, 1996). The fauna include sitatunga (*Tragelaphus spekei*), bushbuck (*T. scriptus*), reedbuck (*Redunca redunca*), waterbuck (*Kobus ellipsiprymnus*), De Brazzas monkey (*Cercopiyhecus neglectus*) (of which a quarter of Kenya population live in this park), the nocturnal potto (*Perodictus potto*) and blue monkeys (*Cercopitherus mitis*). All these species richness is critical for proper planning strategies and for long term conservation of the Park and provision of sustainable ecosystem services to the surrounding communities (Ogutu, 1996).

The Saiwa National Park vegetation consists of three communities: gallery forest (39%), open grassland (24%) and wetland vegetation (37%) (Kavishe, 2001). The principal wetland vegetation consists of reeds and sedges such as *Cyperus latifolius*, large stands of bulrush (*Typha domingensis*), and tall swamp grasses such as *Echinochloa pyramidalis* and *Pycreus lankecus*, interspersed with extensive patches of low vegetation, mainly *Hugrophila spiciformis*, *Ranunculus multifidus* and *Polygonum setulosum* (Kavishe, 2001). The wetland vegetation is bordered by remnants of tropical gallery forest composed of a variety of trees and shrubs including *Ficus* sp., *Phyllanthus* sp., *Acacia* sp., *Albizia* sp., *Termanalia* sp., *Syzigium* and *Hibiscus* sp. The gallery forest gives way to grassland community in the lesser water zone, with species such as *Chloris gayana*, *Sporobolus africanus* and *Setaria* sp (Mohamed, 2000; Kavishe, 2001).

3.2.6 Farming activities within the Watershed

Agriculture (both crop production and animal husbandry) constitutes the main economic activities in the study area. The farming system is a mixture of small-scale farming of maize, wheat, common beans, tea and horticultural crops produced on drained wetlands (Mohamed, 2000).

3.3 Human Population Dynamics and Activities in the Watershed

3.3.1 Population Changes

The Saiwa catchment has seen steady growth in human populations which has resulted in substantial impacts on the Saiwa wetlands, leading to increased demand for wetland resources (Mohamed, 2000). Common practices that affect the wetlands include sub-dividing family farms into smaller land units, draining wetlands, and renting out wetlands mainly for small scale farming (Kamugisha *et al.*, 1997). By people settling in or near wetlands and cultivating areas close to the riverbanks, increased riverbank and soil erosion has resulted in the area (Kamugisha *et al.*, 1997). As noted elsewhere above, the Saiwa Swamp wetlands host important biodiversity. However, this diversity is threatened by intensive agriculture carried out in the catchment area. These threats include encroachment by farmers neighbouring the wetlands, agricultural chemicals transported by runoff from the adjoining farms, and river bank and soil erosion.

The major impacts of this human population increase and changes in land use include the erosion of the banks of the two rivers (Sinyerere and Kipsaina) that feed into the wetlands, and the replacement through ecological succession of the native *Typha* vegetation by elephant grass (Mohamed, 2000). Majority of the people moved into Trans Nzoia County between 1960 and 1970, since then their numbers have increased due to migration and natural birth (GoK, 1989). Major human activities include grain and livestock production and, horticultural practices on drained wetlands. Although the general pattern of land use is similar, there are differences in use which can be attributed to ethnicity, financial ability and preferences of individual farmers (Mohamed, 2000).

The Saiwa wetlands are occupied mostly by households of people of the Bantu origin mainly the Luhya, Kikuyu, Gusii, and Kamba, who are traditionally farmers have drained wetlands for agricultural production. These communities perceive wetlands as habitats that harbour disease-causing parasites such as mosquitoes. Farmers from Nandi, Teso, Luo and Turkana communities who are traditionally engaged in subsistence pastoralism and/or fishing, graze their livestock on wetlands and, engage in subsistence fishing, and extraction of clay for pottery (Mohamed, 2000).

3.3.2 Human activities

There are three major categories of activities on the Saiwa catchment areas that influence resources conservation in the study area. These are waste disposal and agricultural inputs, earth extraction and reclamation of wetlands (Mohamed, 2000). Indirectly, they affect the park by interfering with the chemistry and quantity of water, and hence the park ecology. Organic matter and sediments may find their way into water systems. These substances are released by cattle grazing in marshes and along river banks. While watering, the animals drop urine and excreta into rivers affecting the chemistry of water before it enters the park. This may lead to fluctuation in water chemistry with nutrients leaking from surrounding forest, agricultural farms and emerging urban centres. Additionally, waste oils may come from water pumps, tractors and vehicles that are washed at different sites, especially at Makutano, Kapenguria and Kipsaina towns. This is in additional to pesticides that may come from cattle dips and croplands. Nutrients and sediments from the catchment areas may induce remarkable changes in vegetation structure and composition in the park threatening the role of marshes. Outside the Saiwa Park, earth extraction for brick making is also concentrated on the upper part of Saiwa River, and may be associated with discharge of sediments into the river and its marshes (Ogutu, 1996).

Human activities have major impacts as noted above including the erosion of the banks of the rivers Sinyerere and Kipsaina that feed into the Saiwa wetlands, and the ecological succession of the native *Typha* vegetation by elephant grass (Mohamed, 2000). Without any doubt, intensive agricultural activities are a major threat to the Saiwa wetlands and their biodiversity. For example, agro-chemicals used in the many surrounding farms are carried by runoff into the wetlands, thereby changing the chemistry of the waters, triggering vegetation ecological succession (elephant grass has displaced the native *Typha* vegetation) among other ecological changes (Gichuki, 1998; Mohamed, 2000). The decline in the population of sitatunga antelope in Saiwa National Park is attributed to the elephant grass, which impedes the sitatungas' movements. Furthermore, the bird population and particularly the crane *Balearica regulorum* is attributed to the deterioration of the wetland habitat resulting from inappropriate agricultural practices in the catchment area (Gichuki, 1998).

3.4 General materials and methods

3.4.1 Human Population

Since 1969, Kenya has conducted a national population census every ten years (i.e. 1969, 1979, 1989, 1999 and 2009). To estimate the population of the Saiwa watershed, population projection methods were used (Weeks, 1999). Although initially the population was based on the former administrative districts the current study used Sub-County levels (in conformity with the current status under Constitution of Kenya 2010) as the working units during the inter-census periods.

The population was calculated using the following formulae (Equations 1 and 2):

$$P_{o+t} = P_o(1 + G_{r\,x\,t}) \quad \text{..........Equation 1}$$

$$G_r = [(R_b - R_d) + (I_m - O_m)] \quad \text{..........Equation 2}$$

Where:

P_{o+t} is the total population estimated from the previous census year to the t next year,

P_o is the total population at the census year,

G_r is the growth rate,

R_b and R_d are the birth and death rates at the census date, respectively,

I_m and O_m are the immigration and out-migration rates and

t is the number of years after the census date.

3.4.2 Delineation of soil map of the watershed

The soil map of the Saiwa watershed study area was obtained from the Kapenguria and the Lake Basin Development Authority (LBDA) North Sheet sourced from the Kenya Soil Survey (KSS). The sheets were scanned and georeferenced. The soil units were then digitized and soil rating characteristics were extracted from each of the soil units.

3.4.3 Delineation of land use and land cover changes

The Saiwa watershed was covered by Landsat Path 170 and Row 59. The Pre-processed Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager (OLI) top-of-atmosphere reflectance, orthorectified scenes were obtained in 2018 from the United States Geological Survey (USGS) through Google's Earth Engine. These scenes were level 1 terrain corrected products (L1T) and offered acceptable levels of spatial accuracy, and therefore no geo-rectification was required and image-to-image registration was omitted (Chander *et al.*, 2009). Composite images were processed using available Landsat images at spatial resolution of 30 meters per pixel (Barsi *et al.*, 2014) for each year for the periods of 1985, 1990, 1995, 2000, 2005, 2010 and 2015. In order to remove the influence of clouds, reduce image noise, and fire scars, the median pixel value of the composite image stack was selected to carry out the analysis. This analysis resulted in multi-band images where each pixel represented the median of all unmasked pixels for each band. For 1990, only one image acquisition was available over the study area and was hence excluded in analysis due to high cloud cover percentage.

3.4.3.1 Image Classification and Change Detection

For any supervised classification of land cover images, accurate and sufficient training plot data are crucial. In this study, therefore, six land cover classes were selected in an attempt to capture the main landscape variability based on visual interpretation of Landsat scenes and Google/Bing maps VHR imagery for multiple dates from the year 1985 to 2015 and also based on the ground visits to the area. When choosing training sites, care was taken to use Landsat or Google/Bing imagery captured a year later for a given period. Images from multiple seasons and years were used for choosing the training sites for 1985, 1990, 1995 years.

In this study, determination of changes in land cover between 1985 and 2015 used a supervised classification method that uses Random Forest Technique in R environment (Long *et al.*, 2013). In order to minimize errors in land cover classification, majority analysis using kernel size of 3 by 3 was employed to change spurious pixels within a large single class and smoothing the land cover results (Long *et al.*, 2013). After the supervised classification of imagery, a post-classification change detection algorithm was performed to determine changes in land cover (Yang, 2002; Yuan *et al.*, 2005; Lindquist *et al.*, 2008). This post-classification approach provides statistical evidence on how land cover has changed and is also used to calculate and map land cover changes over any given period of time.

3.4.3.2 Accuracy Assessment

By use of a confusion matrix, the accuracy of the land cover classification was assessed which then compared the classification results to the ground observations. For each land cover class, a contingency matrix table was generated and the overall accuracy, the Kappa statistic or coefficient, and the producer and user accuracies for each class were calculated (Congalton and Green, 2009).

The overall classification accuracy (T) was derived from the table of confusion matrix by counting the number of pixels classified as the same in the satellite image and on the ground (ΣD_{ii}) and dividing this value by the total number of pixels (N) and expressed as a percentage (Equation 3).

$$T = \frac{\Sigma D_{ii}}{N} \text{ .... Equation 3}$$

Where:

ΣD_{ii} is the total number of correctly classified pixels, and

N is the total number of pixels in the error matrix.

The producer's accuracy is a reference based accuracy that is computed by reviewing the predictions produced for a given class and by establishing the percentage of correct predictions (Equation 4).

$$PA = \frac{D_{ij}}{R_i} \text{ .... Equation 4}$$

Where:

PA is the producer's accuracy,

D_{ij} is the number of correctly classified pixels in row i (in the diagonal cell), and

Ri is the total number of pixels in row i.

The purpose of producer's accuracy (PA) is to inform the image analyst of the number of pixels that were correctly classified in a particular category as a percentage of the total number of pixels actually belonging to that category in the image. Producer's accuracy therefore measures errors of omission.

On the other hand, the consumer or user accuracy (CA or UA) is computed using the number of correctly classified pixels to the total number of pixels assigned to a particular category. By telling the consumer that, for all areas identified as category X, a certain percentage are actually correct, it takes errors of commission into account.

The user's or consumer accuracy (CA or UA) is therefore a map-based accuracy that is computed by reviewing the reference data for a class and establishing the percentage of correct predictions for these samples. It is calculated according to the following formula:

$$UA = \frac{D_{ij}}{C_j} \text{..Equation 5}$$

Where:

UA – user's accuracy,

D_{ij} – number of correctly classified pixels in column j (in the diagonal cell), and

C_j – total number of pixels in column j.

A non-parametric Kappa test that accounts for all the elements in the confusion matrix rather than the diagonal elements was used to measure the classification accuracy (Rosenfield and Fitzpatrick-Lins, 1986).

3.5 Chemical properties of water and soils within the Saiwa Swamp

3.5.1 Sampling Points

Seven sampling points were selected based on their relative location within the Saiwa swamp (Figure 3.2). Two sampling points were selected at the entry points of rivers Saiwa and Kipsaina respectively. Sampling Points 4 and 2 were located within the swamp along the main river Saiwa. Sampling Point 3 was located outside the swamp next to an area used for livestock grazing while sampling Point 5 was at a water spring located within the forest whose water flows into the swamp. Sampling Point 7 was selected at the exit of the swamp's water.

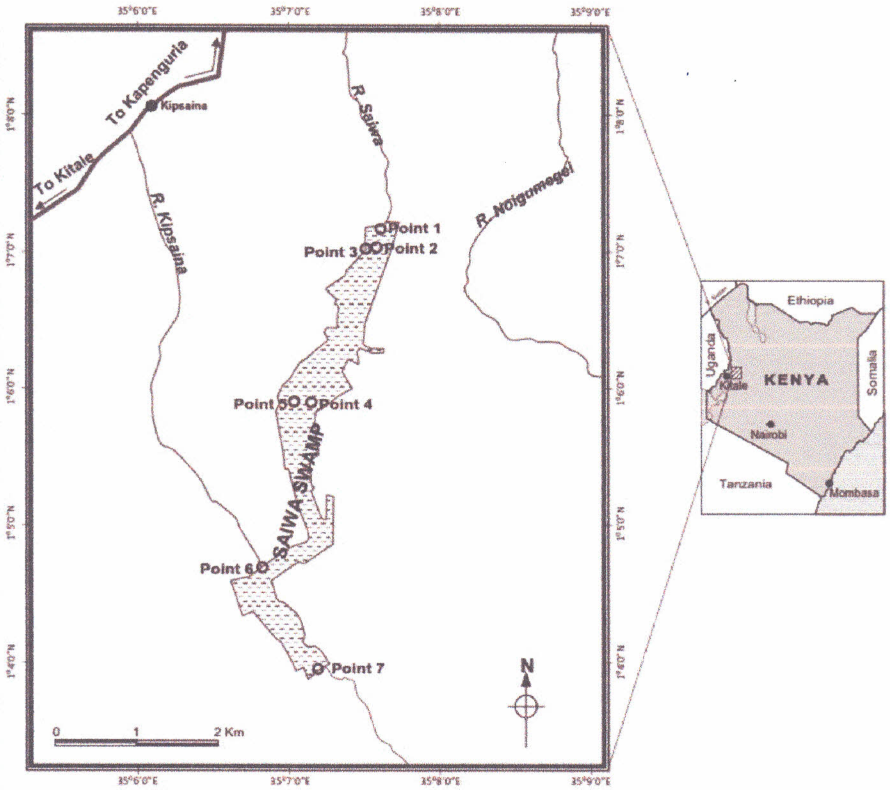


Figure 3.2: Sampling points along the Saiwa swamp

3.5.2 Sampling water and soil for chemical analyses

At each sampling point, three water replicates were collected randomly within an area of 1×1 m of the running river water using 300 ml sterilized plastic bottles. The sample bottles were tightly sealed, placed in an ice cooled container and transported to the Kenya Agricultural & Livestock Research Organization (KARLO) Laboratory, Muguga, for analysis. In the laboratory, the samples were kept in a refrigerator at 4°C awaiting chemical analysis (APHA, 1998). Water samples were collected on monthly basis during wet (April to July and October to December) and dry (January to March and August to October) months from 2014 to 2016 (Plates 4.1 and 4.2).

Plates 4.1: Collection of water samples in the field

Plates 4.2: Sampling for soil sediments in the field.

Separately, soil sediment samples were also collected at bottom of the river from the same water sampling points. Similarly, soil sediment samples were transported in a cooler to the Kenya Agricultural & Livestock Research Organization (KALRO), Muguga laboratory. The soils were thoroughly mixed (to form composite samples), air dried and sieved (through a 2 mm mesh) to remove stone pieces and large root particles. The three water and soil sediment samples were used for detailed analysis of pH, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu), zinc (Zn), Nitrogen (N) manganese (Mn) and sulphur (S) as described by Okalebo *et al.* (2002) and Estefan *et al.* (2013). The sulphate (SO_4) was determined by the turbidity method (APHA, 1998).

3.5.3 Laboratory determination of the chemical properties of water

pH in surface water

Fifty (50) millilitres of the sample water was added to a 250 ml beaker. It was thoroughly mixed for 10 minutes using an electrical shaker and allowed to stand for 30 minutes after which it was stirred again for two minutes. A pH meter with a dual-calomel electrode, standardized with two buffers at pH 4 (acidic) and 7 (alkaline), was used to determine the pH of the water at 20 °C (Okalebo *et al.*, 2002; Estefan *et al*,. 2013).

Minerals (P, S, Ca, K, Mg, Fe, Cu, Mn, Zn) found in surface water

A water sample each of 50mls was taken and transferred to a 75 millilitres digestion tube, and placed in an oven at 100 *°C* for about two hours for the volume to reduce to about 10 millilitres. Then 5 millilitres of the digestion mixture (which consisted of sulphuric acid, hydrogen peroxide, lithium sulphate and selenenium powder) was added. This was to digest the undissolved organic matter. This was then brought to the 75 millilitres mark by adding the digestion mixture (Okalebo *et al.*, 2002; Estefan *et al.*, 2013).

Phosphorus concentration in surface water

Ten (10) millilitres of the digest described in section 4.3.2 was transferred to a 50mls volumetric flasks and this was calibrated to concentration standards of 0, 0.1,0.2, 0.5, 1.0 1.5 and 2 ppm respectively so as to develop the blue colour as per the soils method. The readings were taken from a spectrophotometer at 880nm.

Sulphur concentration in surface water

Ten (10) millilitres of the water sample were pipetted and transferred to a 50 millilitres volumetric flask. Two (2) millilitres of gelatin-barium chloride mixture was added to the 10 mls of water sample. Water was then added to the mixture to make the 50 millilitres mark. The turbidity of the solution was measured at 420nm on a UV/Visible spectrophotometer after 30 minutes preceded by a set of calibration standards.

Magnesium concentration in surface water

Ten (10) millilitres of the digest were pipetted and transferred to a 50 millilitres volumetric flask and 10 millilitres of 5000 ppm strontium chloride was added to make to the 50 millilitres mark. Measurements were taken with an atomic absorption spectrophotometer at 285.2 nm starting with a set of standards.

Iron, Copper, Manganese and Zinc Concentrations in surface water

The digest prepared in Section 3.5.3.2 were measured at wavelengths of 248.3, 324.8, 279.5 and 213.9 nm for iron, copper, manganese and zinc respectively in an atomic absorption spetrophotomer (AAS) starting with a set of calibration standards.

Total Nitrogen Concentration in surface water

Determination of total nitrogen levels was done using the Kjeldahl procedure (Okalebo *et al.*, 2002; Estefan *et al.* 2013). Ten (10) millitres of the water sample aliquot was pippeted and transferred into a 100 ml distillation flask. The water sample was digested in concentrated H_2SO_4 with a catalyst mixture to raise the boiling temperature and to promote the conversion from organic-N to ammonium-N. Ten (10) millitres of 10 *N* NaOH solution was then added in the mixture in order to trap the liberated ammonia gas in 1% Boric acid. The distillate was then collected in saturated (1%) H_3BO_3; and thereafter titrated with dilute standardized **0.01** ***N*** H_2SO_4 to pH 5.0.

Exchangeable Potassium and Calcium in surface water

Exchangeable calcium and potassium were determined using methods described by Okalebo *et al.* (2002). Ten (10) ml of the sample water was shaken for 30 minutes and thereafter filtered through No. 42 Whatman® filter paper. Five (5) ml of the water sample were pipetted into a 50 ml volumetric flask. One millilitre of 26.8% lanthanum chloride solution was thereafter added and the contents diluted to the 50 ml mark of the beaker with 1 M NH_4OAc solution. The concentration of Potassium (K) in the standard sample and blank solutions was determined using a flame photometer, followed by atomic absorption spectrometry for Calcium. The emission readings of the blank and standards were used to construct a standard curve for each element that determined the concentrations of K and Ca in the water samples using the following equation:

$$\text{K or Ca (mg/kg)} = \frac{(C \times V \times f)}{V_2} \quad \text{..Equation 6}$$

Where,

C = concentration of K or Ca,

V = volume of the sample water (5ml),

V_2 = Volume of the original water (10ml), and

f = dilution factor.

3.6 Laboratory determination of the chemical properties of soil sediments

pH in soil sediments

Fifty (50) ml of deionised water was added to 20 g of air dried soil sediment sample passed under 2 mm sieve. The soil and water were mixed for 10 minutes using an electrical shaker and allowed to stand for 30 minutes after which it was stirred again for two minutes. A pH meter with a dual-calomel electrode was standardized with two buffers at pH 4 and 7 and used to determine the pH of the supernatant at 20 °C (Okalebo *et al.*, 2002; Estefan *et al.*, 2013).

Available soil phosphorus

The Olsen method was used to determine the extractable soil sediment phosphorus (Okalebo *et al.*, 2002; Estefan *et al.*, 2013). A 2.5 g sample of air-dried (2mm) soil/sediment was weighed into a 250 ml plastic bottle. Fifty (50) ml of the Olsen's extracting solution (0.5 M $NaHCO_3$ at pH 8.5) was added to each bottle. The contents were mixed on a mechanical shaker for 30 minutes and thereafter the suspension was filtered through Whatman® No. 42 filter paper. The filtrate was used for colorimetric phosphorus measurement. The concentration of phosphorus (ppm) in the solution was obtained from the standard calibration curve, making corrections for reagent blank P concentrations. The concentration of phosphorus in the sample was calculated as follows:

$$\text{Olsen P, mg/kg} = \frac{c \, x \, v}{w} \quad \text{...Equation 7}$$

Where:

c = concentration of P in the sample,

V = volume of extractant, and

w = weight of soil sediment sample.

Total nitrogen

For soil sediments, the colorimetric method was used to determine total nitrogen (Okalebo *et al.*, 2002; Estefan *et al.*, 2013). In the laboratory, an oven dried (105 °C) ground (<0.25 mm, 60 mesh) soil sediment sample weighing 0.3 g was placed into a labelled, dry and clean digestion tube. A 2.5 millilitre digestion mixture (made up of 3.2 g salicylic acid in 100 ml of sulphuric acid-selenium mixture) was added to each tube and the reagent blanks for each batch of the samples. Digestion was done at 110 °C for 1 hour. The temperature of the mixture was then raised to 330 °C and heating continued until the solution turned colourless. The tubes were allowed to cool and the contents diluted to 100 ml with distilled water and allowed to settle so that a clear solution was taken from the top of the test tube for analysis. The nitrogen concentration in the sample material, expressed as % N, was calculated as follows:

$$\text{Total (\%) N} = \frac{c \, x \, 0.01}{w} \quad \text{...Equation 8}$$

Where:

c = concentration of N in the sample, and

w = weight of soil sediment sample (g).

Exchangeable calcium and potassium

Exchangeable, calcium and potassium were determined following the methods described by Okalebo *et al.* (2002) and Estefan *et al.* (2013). A five (5) g sample of air dry soil sediments (<2 mm) of was weighed into a clean plastic bottle with a stopper. One hundred (100) millilitres of 1 M ammonium acetate (NH_4OAc) solution at pH 7 was added. The contents were shaken for 30 minutes and filtered through No. 42 Whatman® filter paper. Five (5) ml of the soil/sediment extract solution were pipetted into a 50 ml volumetric flask. One (1) millilitre of 26.8% lanthanum chloride solution was added and the contents topped to the 50 ml mark with 1 M NH_4OAc extraction solution. The concentration of Na and K in the standards, sample and blank solutions were determined using a flame photometer, followed by atomic absorption spectrometry for Ca. The emission readings of the blank and standards were used to construct a standard curve to determine the concentration of Na, Ca and K in the soil sediment sample and calculated as follows:

$$\text{Na, Ca or K (mg/kg)} = \frac{(c \; x \; v \; x \; f)}{w} \quad \text{..................................Equation 9}$$

Where:

c = concentration of Na, Ca or K in the sample extract,

v = volume of the extract solution,

w = weight of the soil sediment sample (g), and

f = dilution factor.

Iron concentration in soil sediments

The concentration of iron in a dried soil sediments sample was determined by first preparing a selenium-sulphuric acid solution through dissolving 3.5 g selenium powder in 100 ml concentrated sulphuric acid in a beaker (Okalebo *et al.*, 2002; Estefan *et al.*, 2013). The selenium-sulphuric acid solution was then heated at 300 °C while covering the beaker with a watch glass and allowed to react at room temperature for 2 hours. The final digestion mixture was then prepared by dissolving 7.2 g salicylic acid in 100 ml of the selenium-sulphuric acid mixture. The concentration of iron in the dried sample was then calculated as follows:

$$\text{Fe (mg/kg)} = \frac{(c \times v \times f)}{w} \quad \text{.......................................Equation 10}$$

Where:

c = concentration of Fe in the sample solution,

v = final volume of the digest process,

w = weight of the soil sample (g), and

f = the dilution factor.

Sulphate concentration in soil sediments

The SO_4^{2-} in the solution was determined by the turbidity method as described by APHA (1998), Okalebo *et al.* (2002) and Estefan *et al.* (2013). Precisely 5 g of air dried soil sediment samples were weighed into a centrifuge tube. Twenty five (25) millilitres of potassium orthophosphate extracting solution (0.5491 g of KH_2PO_4 in 1 litre of distilled water) were added. The suspension was thereafter filtered through a Whatman® filter paper No. 42. The amount of sulphur in the dried soil sediments sample was calculated as follows:

$$\text{S (mg/kg)} = \frac{(c \times v \times f)}{w} \quad \text{......................................Equation 11}$$

Where:

c = concentration of S in the solution,

v = final volume of the sample digest,

w = weight of soil sediment sample (g), and

f = dilution factor.

3.7 Determination of the plant species present within the Saiwa Swamp National Park

At each of the sampling points used for the soil sediments and water chemical assessment, a list of all plant species (floristic list), was compiled. The list was determined by a walk-through method taken through the vegetation area with a goal of identifying all the plant species present as described by Pinheiro and Monteiro (2006), Carter *et al.* (2007) and Rauenhorst (2016). The floristic list was compiled during the wet and dry seasons. In addition to compiling a species list, voucher specimens were collected for future verification of the past and current plant species found in the study area (Goldblatt *et al.*, 1992; Funk *et al.*, 2005; Carter *et al.*, 2007).

3.8 Statistical analysis on land use and land cover changes

Land use and land cover changes were analysed using the Kappa statistic in which the coefficient was calculated as indicated in Equation 12.

$$\widehat{K} = \frac{\sum_{\substack{i=1\\j=1}}^{m} D_{ij} \times \sum_{\substack{i=1\\j=1}}^{m} R_i \times C_j}{N^2 - \sum_{\substack{i=1\\j=1}}^{m} R_i \times C_j} \quad \text{..Equation 12}$$

Where:

$\widehat{K}$ = the Kappa-coefficient,

N = total number of pixels,

m = number of classes,

$\sum D_{ij}$ = total diagonal elements of an error matrix (the sum of correctly classified pixels in all images), and

R_i = total number of pixels in row i, C_j – total number of pixels in column j.

3.9 Statistical analysis on water and soil sediments chemical data

Analysis of Variance (ANOVA) was used to test Nutrient levels using GenStat Release 12.1 statistical software (GenStat, 2009). Least significant difference (LSD) was used for mean separation at 5% significance level (Steel *et al.*, 1997; Moore and McCabe, 1999; Zar, 2001).

CHAPTER 4: POPULATION DYNAMICS, LAND USE AND LAND-COVER CHANGES IN THE SAIWA SWAMP WATERSHED

4.1 Introduction

This chapter discusses the methods, results and analyses of the land use and land cover changes in the watershed of Saiwa Swamp in the last three decades. In particular, it addresses the population dynamics, soils, and the land use and land cover changes (LULC) in the watershed which is the main water catchment of Saiwa Swamp National Park. It was postulated that the increase in human population and related human activities would have impacts on the watershed and this would ultimately affect Saiwa Swamp. A better understanding of the various human activities in the larger watershed area would provide the pre-requisite knowledge on how to mitigate negative human impacts on of the watershed area and Saiwa Swamp in particular.

4.2 Study Area

The Saiwa Swamp watershed study area, is situated within the Trans Nzoia and West Pokot counties with a small portion in the east that falls within the county of Elgeyo Marakwet of Kenya. It is bounded by latitudes 1.1° and 1.3° N and longitudes 35.0° and 35.2° E (See Figure 3.1). The watershed boundaries were derived from a digital elevation model with 30m spatial resolution and delineate an area of about 27500 hectares. The watershed is drained by Saiwa and Sitatunga rivers that feed the Nzoia river system, which flows into Lake Victoria.

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4.3 Materials and Methods

4.3.1 Estimation of population and soil maps

To estimate the population of each individual former districts during the inter-census periods (1979, 1989, 1999 and 2009), population projections methods by Weeks (1999) were used while soil map of the study area was obtained from Kapenguria and the Lake Basin Development Authority (LBDA), north sheet sourced from the Kenya soil survey. The sheets were scanned and georeferenced (See Chapter 3).

4.3.2 Landsat Images Acquisition and Processing

Pre-processed Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager (OLI), top-of-atmosphere reflectance and orthorectified scenes were obtained in 2018 from the USGS through Google's Earth Engine. These scenes classified as level 1 terrain corrected products (L1T) and offer acceptable levels of spatial accuracy, therefore no geo-rectification was required and image-to-image registration was omitted as described by Chander *et al.* (2009). Composite images were processed using available Landsat images for each year for the periods of 1985, 1990, 1995, 2000, 2005, 2010 and 2015.

4.3.3 Classification and Change Detection

Since accurate and sufficient training plot data are crucial for a supervised classification, six land cover classes were selected to capture the main landscape variability based on visual interpretation of Landsat scenes and Google/Bing maps VHR imagery (multiple dates, 2000–2015) and through on the ground visits to the area. Images from multiple seasons and years were used for choosing training sites for periods older than 2000.

Machine-learning techniques, including Classification and Regression Trees (CART) and Random Forest (RF) were used (Gislason *et al.*, 2006). Changes in land cover between 1985 and 2015 were determined using a supervised classification method that uses random forest technique in R environment. In order to minimize errors in land cover classification, majority analysis using kernel size of 3 by 3 was employed to change spurious pixels within a large single class and smoothing the land cover results. The accuracy of the land cover classification was assessed using a confusion matrix that compared the classification results to the ground observation using the Kappa statistic (Congalton and Green 2009).

4.4 Results

4.4.1 Soils within the Saiwa watershed

The results showed that the Saiwa watershed is composed of different soil types (Figure 4.1). Rhodic Ferralsols soils were the most common soil type occupying 46.86% of the study area followed by Ferralo-orthic Acrisols + ferralo-humic Acrisols at 21.72% while Gleysols occupy 13.63%. Eutric Planosols and haplic Phaeozems to Humic Cambisols which occur in the hilly and steep slopes of the area North of Kapenguria recorded lowest percentages of 0.13% and 0.91% respectively.

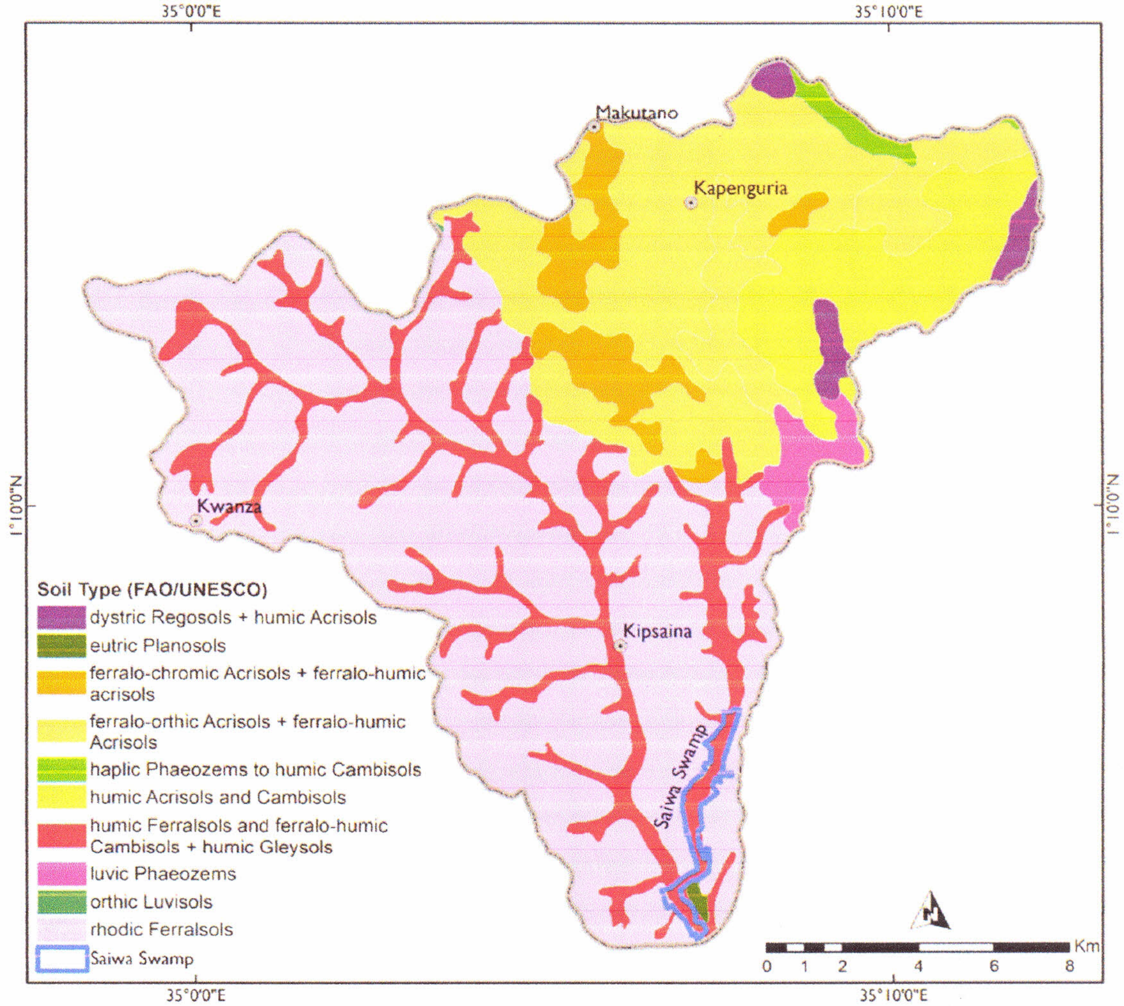

Figure 4.1: Soil map of Saiwa Swamp Watershed

The relative proportion of each soil type in the study area is presented as a percentage in Table 4.1.

2.6% and 2.9% respectively (Table 4.2). The population was projected to increase to 949,359 in 2013 and to 1,100,795 persons by 2017. In terms of gender, the population in the year 2017 was projected to comprise of 547,431 males and 553,364 females. The relative proportion of population in the watershed is shown in Figure 4.2.

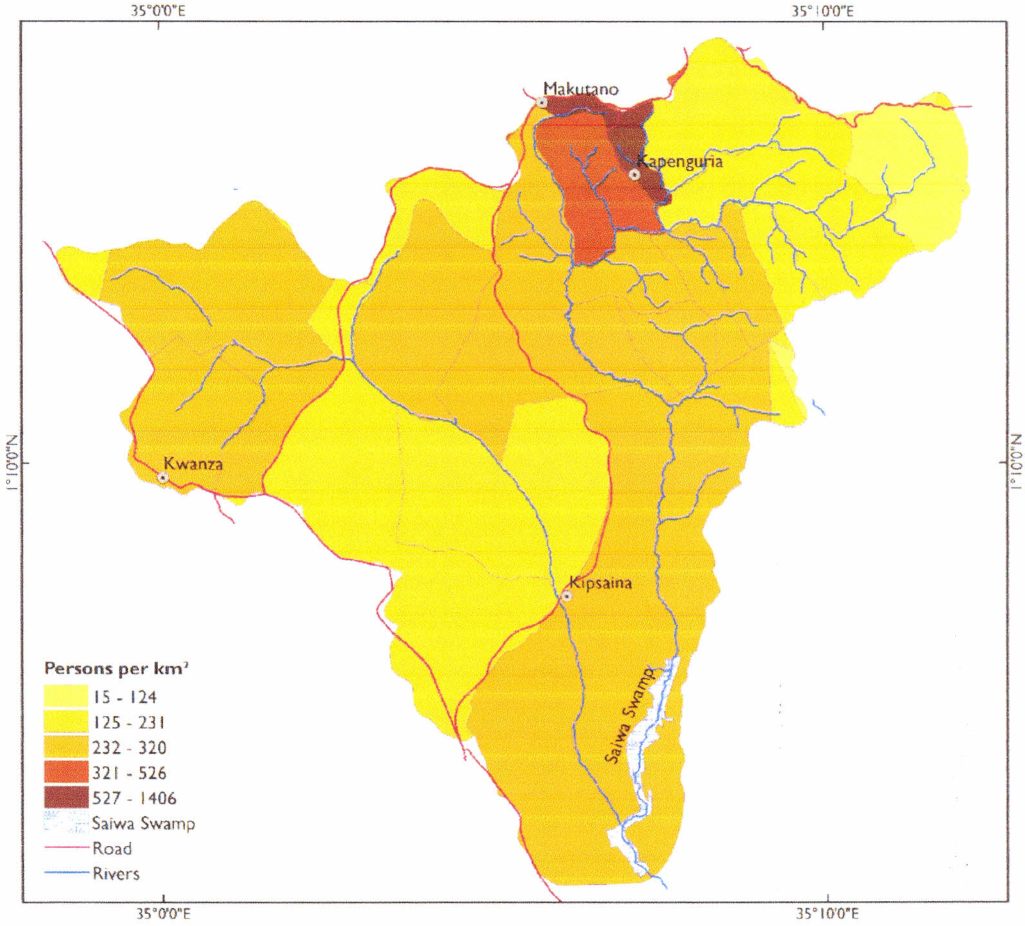

Figure 4.2: Population Density of the Saiwa Watershed based on 2009 Census.

4.4.3 Land use and land cover changes

The changes and trends of each land use and land cover of the study area between the period 1985 and 2015 as noted above are shown in Figure 4.3. In this figure, the trends are clearly notable

Table 4.1: The soils and their extent of coverage in Saiwa watershed

Soil Type	Area (ha)	% Cover
Dystric Regosols + Humic Acrisols	453.71	1.65
Eutric Planosols	36.10	0.13
Ferralo-Chromic Acrisols + Ferralo-Humic Acrisols	1351.89	4.91
Ferralo-Orthic Acrisols + Ferralo-Humic Acrisols	5983.96	21.72
Haplic Phaeozems to Humic Cambisols	249.58	0.91
Humic Acrisols and Cambisols	2355.71	8.55
Humic Ferralsols and Ferralo-Humic Cambisols + Humic Gleysols	3755.81	13.63
Luvic Phaeozems	447.35	1.62
Orthic Luvisols	7.36	0.03
Rhodic Ferralsols	12910.88	46.86

4.4.2 Population Dynamics

The total population of Saiwa watershed increased at a rate of 11.8 per cent per year from about 72,585 in 1999 to 91998 in 2009 census periods a rate that is above the national growth rate of 2.5% (Table 4.2). Increase in population resulted in a shift of population density from about 200 inhabitants/km^2 in 1999 to 254 inhabitants/km^2 in 2009 (GoK, 2009).

Table 4.2: Population size, average household size and annual growth rates in Saiwa watershed.

County	Sub-County	Census 1999	Census 2009	Household Size	Growth Rate per annum
Trans Nzoia	Kaplamai	9779	12466	4.8	2.7
Trans Nzoia	Kwanza	15176	19769	5.2	3.0
West Pokot	Kapenguria	30844	38795	5.3	2.6
Elgeyo Marakwet	Elgeyo Marakwet West	16786	20968	5.7	2.9

The intercensal growth rates for Kaplamai and Kwanza sub-counties of Trans Nzoia was 2.7 and 3.0 percent between 1999 and 2009, while that of Kapenguria and Elgeyo Marakwet West were especially for forests and woodlands. Temporal changes in land use and land cover calculated from the maps in Figure 4.3 are contained in Table 4.3.

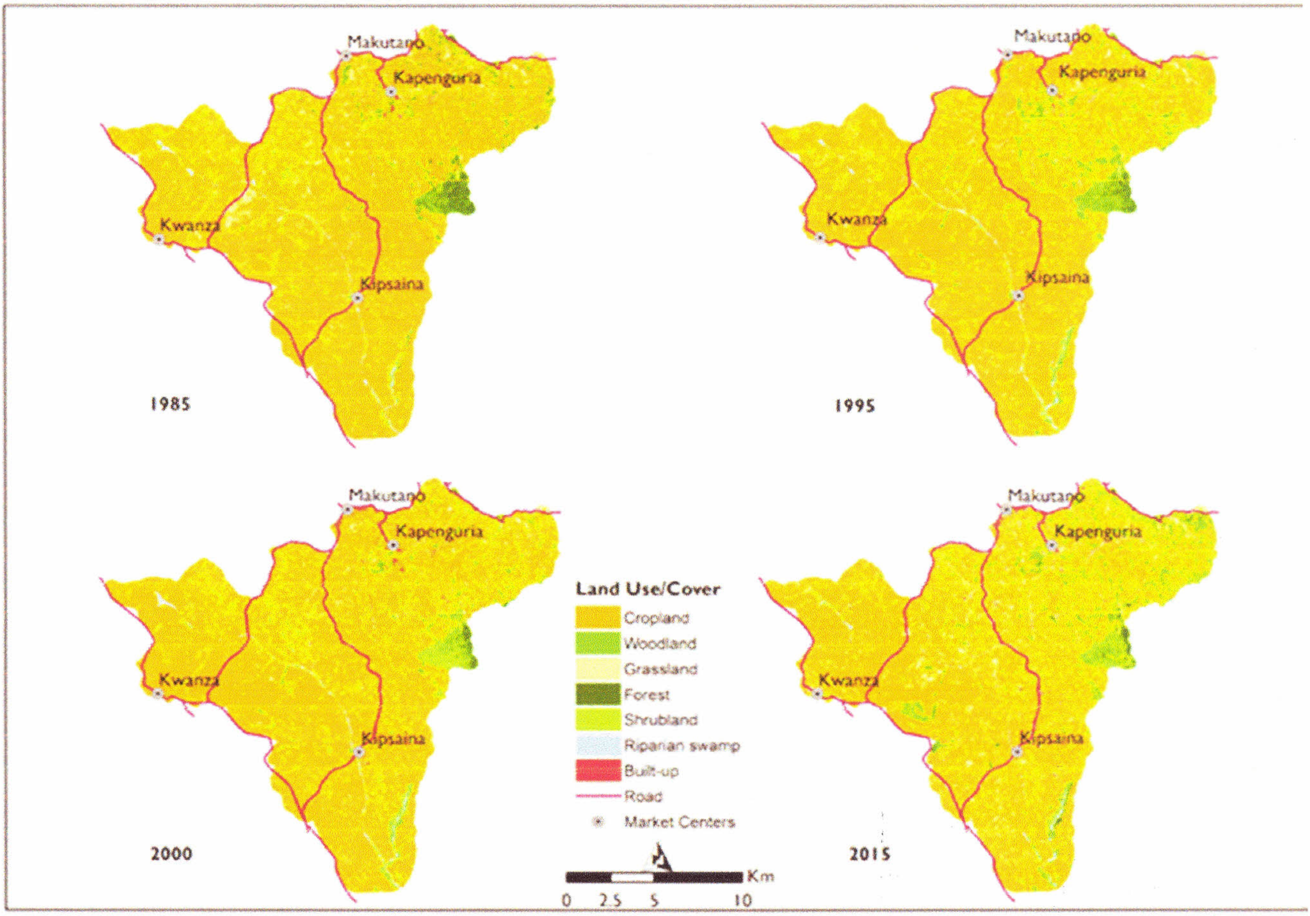

Figure 4.3: Land Cover Classifications from 1985 – 2015

In the case of forest cover, there was a sharp decrease between 1985 and 2000 from 3.05% to 0.54%. However, the forest cover increased sharply from 0.54% to 1.15% between the years 2000 and 2015. In the case of the shrubland cover there were no notable major changes between the years 1985 to 2015 (Table 4.3). However, between 1985 and 2000 there was a marginal change from 12.90% to 16.18%. For the riparian cover the trend in cover change was similar to that of cropland cover in that it remained almost the same between 1985 and 2000. But it then decreased from 191 hectares to 130 hectares, a decline of 31.4% between the years 2000 to 2015.

Between the year 1985 and 1995 there was no notable change in the cover of built up areas, however, between 1995 and 2015, there was a sustained increase in built up areas from 99 hectares in 1995 to 157 hectares in 2000 and 223 hectares in 2015, which was a change of 125% (Table 4.3).

4.4.4 Use of Confusion Matrices to Ascertain Model Accuracy

A confusion matrix is a table that is used to describe the performance or the accuracy of this study's prediction of the classification model. The table tries to show whether the information obtained from the Landsat imageries/models reflects how accurate the model is in predicting the actual situation on the ground. For example using the confusion matrix table for 1985, it was possible to tell the accuracy of this study's prediction as 79%. For other years (see Table 4.4-4.7) the predictions were 79% (1985), 84% (1995 and 2000) and 81% for 2015. Results (see Table 4.4-4.7) from this study showed that the Kappa coefficient values obtained from the confusion matrices were 0.732, 0.792, 0.790 and 0.746 for years 1985, 1995, 2000 and 2015 respectively. On average the user's accuracy ranged from 68.7% to 92.2% while the producer's accuracy ranged from 41.6% to 94.1%.

Table 4.410: Confusion Matrix for Land Cover Classification, 1985 (OOB (out-of-bag) error rate estimate: 20.91%)

	Reference data								Accuracy criteria	
Classifier data	Cropland	Woodland	Grassland	Forest	Shrubland	Riparian	Built-up	Row total pixels	Producer's accuracy (%)	User's accuracy (%)
Cropland	**1146**	3	26	2	39	20	1	1237	92.6	80.4
Woodland	17	**146**	0	96	22	9	0	290	50.3	68.9
Grassland	67	0	**401**	3	20	0	8	499	80.4	87.7
Forest	4	35	0	**460**	23	1	0	523	88.0	75.9
Shrubland	66	22	18	43	**410**	16	3	578	70.9	75.8
Riparian	84	6	1	2	23	**123**	0	239	51.5	72.4
Built-up	41	0	11	0	4	1	**101**	158	63.9	89.4
Column total pixels	1425	212	457	606	541	170	113	3524		

Note: - The bolded values represent number of correctly classified pixels (D_{ii}).
- Overall classification accuracy (T): 79%
- Kappa statistics: 0.732

Table 4.511: Confusion Matrix for Land Cover Classification, 1995 (OOB (out-of-bag) error rate estimate: 16.01%).

	Reference data								Accuracy criteria	
Classifier data	Cropland	Woodland	Grassland	Forest	Shrubland	Riparian	Built-up	Row total pixels	Producer's accuracy (%)	User's accuracy (%)
Cropland	**1170**	15	11	0	29	12	1	1238	94.5	85.3
Woodland	19	**340**	0	25	16	11	0	411	82.7	77.3
Grassland	32	3	**407**	0	8	0	6	456	89.3	89.6
Forest	0	40	0	**191**	9	0	0	240	79.6	84.5
Shrubland	100	24	20	10	**429**	14	1	598	71.7	81.4
Riparian	33	18	1	0	24	**102**	1	179	57.0	73.4
Built-up	18	0	15	0	12	0	**131**	176	74.4	93.6
Column total pixels	1372	440	454	226	527	139	140	3298		

Note: -The highlighted values represent number of correctly classified pixels (D_{ii}).
- Overall classification accuracy (T): 84%
- Kappa statistics: 0.792

Table 4.6: Confusion Matrix for Land Cover Classification, 2000 (OOB (out-of-bag) error rate estimate: 16.14%).

	Reference data								Accuracy criteria	
Classifier data	Cropland	Woodland	Grassland	Forest	Shrubland	Riparian	Built-up	Row total pixels	Producer's accuracy (%)	User's accuracy (%)
Cropland	**1300**	5	12	0	29	6	8	1360	95.6	88.5
Woodland	23	**270**	0	51	27	16	0	387	69.8	72.6
Grassland	19	1	**367**	0	16	2	7	412	89.1	92.4
Forest	0	44	0	**237**	8	0	0	289	82.0	82.3
Shrubland	25	37	4	0	**528**	24	3	621	85.0	78.0
Riparian	89	15	1	0	51	**83**	0	239	34.7	63.4
Built-up	13	0	13	0	18	0	**162**	206	78.6	90.0
Column total pixels	1469	372	397	288	677	131	180	3514		

Note: - The highlighted values represent number of correctly classified pixels (D_{ii}).
- Overall classification accuracy (T): 84%.
- Kappa statistics: 0.790.

Table 4.7: Confusion Matrix for Land Cover Classification, 2015 (OOB (out-of-bag) error rate estimate: 19.41%).

	Reference data								Accuracy criteria	
Classifier data	Cropland	Woodland	Grassland	Forest	Shrubland	Riparian	Built-up	Row total pixels	Producer's accuracy (%)	User's accuracy (%)
Cropland	**1162**	16	21	0	29	11	0	1239	93.8	80.0
Woodland	47	**155**	3	10	45	5	7	272	57.0	68.3
Grassland	67	0	**402**	3	19	1	7	499	80.6	84.5
Forest	0	3	1	**250**	12	1	0	267	93.6	90.6
Shrubland	47	32	22	10	**474**	11	2	598	79.3	77.6
Riparian	129	20	4	3	27	**55**	0	238	23.1	65.5
Built-up	1	1	23	0	5	0	**180**	210	85.7	91.8
Column total pixels	1453	227	476	276	611	84	196	3323		

Note: - The highlighted values represent number of correctly classified pixels (D_{ii}).
- Overall classification accuracy (T): 81%.
- Kappa statistics: 0.746.

4.5 Discussion

4.5.1 Soils of the study area

From the results it was observed that the study area is composed of different soil types largely dominated by Rhodic Ferralsols soils which occupies 46.86% followed by Ferralo-Orthic Acrisols + Ferralo-Humic Acrisols which occupies 21.72% of the total catchment. The Ferralsols soils are complex of well drained, shallow to deep, dark red to strong brown, friable gravelly sandy clay to clay. These soils are developed from intermediate igneous rocks (phonolites, syenites and trachytes). Most of the soils in the catchment area are acidic and have moderate to low soil fertility except for some parts around Kwanza and the river valleys (Jaetzold and Schmidt, 1983.). In the study area, these soils support largely cultivation of maize (Jaetzold and Schmidt, 1983; Kanyanjua *et al.*, 2002). This is supported by the fact that acid soils in Kenya are found in areas of high rainfall, potentially suitable for maize production. In Kenya, acidic and low-fertility soils, particularly with low available P and N, are the major causes of low and declining maize yields (Jaetzold and Schmidt, 1983; Kanyanjua *et al.*, 2002). Soils in the once fertile high potential zones in Kenya have continued to lose fertility as a result of a number of factors including mono cropping, inadequate inorganic and organic fertilizer use and soil erosion among others especially among the small scale maize producers (Kanyanjua *et al.*, 2002). Poor agriculture in the extreme north of the watershed could be attributed to the Ferralsols soils which are found in this area.

4.5.2 Population Dynamics

The total population of Saiwa watershed was found to increase at a rate of 3 per cent per year from 57,800 in 1999 to 73,042 in 2009 census periods (See Table 4.2). This increase of 3% per annum of human population is above the estimated national growth rate of 2.5% per annum in Kenya. Increase in population resulted in a shift of population density from about 200/km^2

in 1999 to 225 inhabitants/km^2 in 2009. According to Bright *et al.* (2017), the Saiwa watershed population was projected to increase to about 104,772 persons in 2016 and the average household size at 5, which is 20% larger than the national average household size of 4.4 (GoK, 2009). This increase in population especially within the watershed has negative implications on the sustainability of the watershed through activities such as deforestation, soil erosion and depletion of natural resources.

Increase in population also has other underlying effects such as the interference of the water course ways and loss of the more adaptable indigenous vegetation which has the capacity to withhold water (Kithiia, 2006). Work of Sahin and Hall (1996) shows that when natural vegetation is cleared or degraded, surface run-off and river discharge increase, triggering extreme flooding events and soil erosion.

In the Saiwa watershed, like in many parts of the developing countries, increase in population results in increase in urbanization. This is evident in the study area in that areas close to market places, such as Kapenguria and Makutano, are surrounded by higher densities of human populations than farmlands (See Figure 4.2).

Results of population changes in the catchment area are found in Table 4.2. Some factors that may have contributed to this population change within the watershed include human immigration into the watershed, fragmentation of the large former colonial "White Highlands" farms to small scale farms that are able to settle more people, and the general evolution of land use in Kenya that is more flexible allowing people to settle in many different land use areas (Cone and Lipscomb, 1972). Before the colonial era, land had been zoned into specific areas for specific crops depending on rainfall variability. Prior to the emergence of the colonial regime, it was generally believed that the Kenyan highlands soil fertility was inexhaustible but it was later realized that this was not the case which led to the introduction of inorganic fertilizers to sustain crop productivity.

In the northern part of the study area (northeast of Kapenguria), the area is very hilly with poor and shallow soils (Jaetzold and Schmidt, 1983) and is less populated compared to other areas due to low farming activities that are not able to support high population. The area is basically utilized for growing trees.

The area surrounding the Saiwa swamp has moderate population of 232 – 320 per Km^2. This could be attributed to the two settlement schemes (Saiwa and Kipsaina) which inhabited by people from different ethnic communities which include, Kikuyus, Kambas, Luyas, Nandi Luos and Kisii. Others are Teso and Turkana. Majority of the immigrants moved into the area between 1960 and 1970 and their numbers have since increased due to more and more immigration and natural birth (GoK, 2009).

4.5.3 Land Use -Land cover Changes

The findings of the study (Figure 4.3 and Table 4.3) showed that both the land use and land cover fluctuated over the study period within the watershed. The study showed that the area under crops between 1985 and 2000 remained almost the same but declined sharply between 2000 and 2015. Although no concrete facts have been established as the driving force for this decline, it is presumed that conversion of cropland to other categories of land use one of them being the conversion to built-up areas due to urbanization resulting from increase in population among others (Bilsborrow and Okoth-Ogendo (1992). It was also observed that during the pre-colonial period, large scale farming was dominant which was later replaced by the small scale farming following the sub-division after independence in 1963. This sub-division attracted more immigrants into the area resulting in more land being converted into smaller farm units for settlement leading to reduced overall farmland cover. The findings of this study however, were in variance with those of Bilsborrow and Delargy (1991), who found that human population growth positively correlates with land use intensification, expansion of agricultural land and deforestation in the developing countries.

Another factor that can closely be linked to decline in cropland cover is the establishment of woodlots. From the study, it was observed that the shrinking cropland area corresponds closely with the increasing area under woodland as observed between 2000 and 2015. It was notable (Figure 4.3 and Table 4.3) that the area under woodland cover fluctuated over the study period from 2.40% to 4.31% between 1985 and 1995 and increased from 2.68% to 7.6% between 2000 and 2015. The decline of woodlands from 1985 to 1995 could be explained by the severe drought of 1984 and 1985 and the general clearance of vegetation especially felling of trees for farming, settlement and charcoal burning. However, the cover of woodlands increased sharply between 2000 and 2015 mainly due to improved establishment of woodlots, e.g. planting of exotic trees such as Eucalyptus, wattle trees and Cypress which grow faster than the indigenous tree species and had high economic returns. This was further boosted by a government policy on tree planting. Examples of extensive woodlots were especially noted in Kwanza and Kaplamai sub-counties of Trans Nzoia County and Kapenguria in West Pokot County.

In the case of grassland cover, it was notable that the cover, like that of woodlands, fluctuated over the same study period from 5.25% to 3.81% between 1985 and 1995 and increased from 3.81% to 8.95% between 2000 and 2015. The initial decline of the grassland cover could be attributed to the drought that was experienced between 1984 and 1985 and the conversion of grasslands to farmlands and woodlands through agroforestry practices. The increase in grassland cover between 2000 and 2015 could be linked to enhanced fodder farming as a result of increased dairy farming in the area (Kipkorir, 2017).

The study also found that the relative forest cover showed a steady declined from 3.05% in 1985 to 1.15% in 2015. This sharp increase in forest cover was linked to increased planting of woodlots and on the government policy of tree planting in order to attain the 10% forest cover as a requirement by the United Nations for member countries (FAO, 2006).

While the area under shrubland was found to have the second largest land cover (15.51%) after cropland (65.43%), there were no notable major changes in shrubland, its cover remained almost the same (around 15%) between 1995 and 2015. The relatively stable state of shrubland cover could be attributed to the nature of the vegetation type. In East Africa, shrubland is described as "a plant community characterised by vegetation dominated by shrubs, which may either occur naturally or as a result of human activity" (Pratt and Gwynne, 1977). In the current study, the shrubland remained stable as observed by Simute (1992) who found that in most cases shrublands remain in their stable state due to regular natural disturbance such as fire and browsing. Shrublands were mostly found in the northern part of the study area where the mainstay activity is raising of pastoral livestock especially sheep and goats.

However, the riparian cover remained relatively stable, around 0.7% for close to ten years but decreased from 222 ha to 130 ha between the years 2000 to 2015, a decrease of about 50%. This decrease could be associated with the encroachment of the riparian land by farmers for growing of vegetables and horticultural crops.

The findings of land use and land cover (see Table 4.3) also revealed that the built-up environment has been on an upward trend and this could be explained by the general increase in urbanization; emergence of new markets along the roads and the general increase in settlement in response to population growth. In particular the built-up area is clearly observed along the roads leading to major markets and at the markets of Kapenguria and Makutano. According to Cohen (1999), developing countries, especially in Africa have the highest rate of rural to urban migration in the world. Africa has an urbanization rate of 4.87% as opposed to 2.57% for the world. The overall growth rate of Kenya's urban population stands at 6% implying very rapid rural to urban migration pattern (GoK, 2009). Much of rural to urban migration is influenced by economic growth and development and by technological change (Marshall *et al.*, 2009). Conflicts and social disruption also contribute to this phenomenon in eastern Africa countries of Kenya, Somalia, Ethiopia and South Sudan as urban centres offer better security compared to rural areas (Holechek *et al.*, 2017).

It can be argued that this rural to urban migration is driven by "**pull factors**" that attract people to urban areas and "**push factors**" that drive people away from the countryside. Employment opportunities in urban areas are one of the main pull factors because many industries are located in urban centres and offer opportunities of high urban wages than rural wages. In urban centres, there are also more educational institutions providing courses and training in a wide range of subjects and skills. Push factors include the poor living conditions, the lack of opportunities for paid employment in rural areas, and lack of security in conflict areas (Holechek *et al.*, 2017). Other factors include poor health care and limited educational and economic opportunities as well as environmental changes, droughts, floods, lack of availability of sufficiently productive land, and other pressures on rural livelihoods (Holechek *et al.*, 2017).

In general, the possible forces driving land-use and land-cover changes can be grouped into six categories namely population, technology, political economy, political structure, attitudes and values (Turner and Meyer, 1991; Stern *et al.*, 1992). Although not all of these factors have a direct effect in land-use/land-covers of the current study area, population, technology and political economy and structure have greatly influence land-use and land-cover in Trans-Nzoia. In many developing countries including Kenya, political economy includes the systems of exchange, ownership, and control of land while political structure involves institutions and organization of governance land ownership. Peoples will therefore respond to economic opportunities, as mediated by these factors which will ultimately drive land-cover changes.

In Kenya, the most significant changes in land use and land cover (LULC) are related to agricultural expansion into other land use areas such as forests and wetlands. This results in decrease in natural vegetation formations such as forests, bush land, grasslands and wetlands (Githui *et al.*, 2009). As a result of increasing human population and increased demand for food and fuel wood, these land use and land cover changes results. While these changes in LULC have allowed to sustain human population growth and economic development in the past, it raises concerns regarding local and regional environmental impacts and its consequences for human well-being.

CHAPTER 5: VARIATIONS IN THE CHEMICAL STATUS OF WATER AND SOIL SEDIMENTS ALONG SAIWA SWAMP

5.1 Introduction

This Chapter presents the seasonal mineral nutrients status in the water flowing into and out of the Saiwa swamp ecosystem. It also presents data on the seasonal mineral nutrients status of soil sediments within the swamp and attempts to link these to human activities in the Saiwa watershed.

5.2 Study Area

The Saiwa watershed is located about 400 km west of Nairobi. Saiwa Swamp is situated in a watershed that is experiencing increasing human populations and farming activities (especially for maize which is the staple food crop in Kenya) that, if not checked, may cause severe ecological impacts). The park is situated 25 km north-east of Kitale Town (01° 05' N, 35° 07' E), at an elevation of about 1860m asl. The swamp is located at the confluence of rivers Saiwa, which originates from the Cherengany ranges (3371m asl) to the north, and river Kipsaina which originates from Mt. Elgon (4321m asl) to the west. The two rivers join to form river Sinyerere that flows into river Nzoia further downstream and drains into Lake Vctoria (Ogutu, 1996).

5.3 Materials and Methods

Sampling points were selected based on their relative location within the swamp. Two sampling points, point 1 (1° 7.015' N, 35° 7.66' E) and point 6 (1° 4.53' N, 35° 6.6.86' E), were selected at the entry points of rivers Saiwa and Kipsaina respectively. Sampling point 4 (1° 5.73' N, 35° 7.20' E) and point 2 (1° 6.84' N, 35° 7.55' E) were located within the swamp along the main River

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5.4 Results

5.4.1 Nutrients concentrations in Saiwa swamp surface water

pH levels in surface water

pH levels for surface water were not significantly ($p>0.05$) different between the dry and wet seasons (Figure 5.1). During the two seasons, pH ranged from slightly acidic (6.3) to slightly alkaline (7.4) (Figure 5.1). Dry season pH ranged from pH 6.7±0.3 to 7.4±0.5 at Sampling Points 1 and 6, (overall mean of 7.1±0.3) while wet season pH ranged from pH 6.3±0.3 to 7.5±0.3 at Sampling Points 1 and 7 respectively (overall mean of 7.0±0.2). Sampling Point 3 registered neutral pH (7.0±0.2) during the seasons (Figure 5.1).

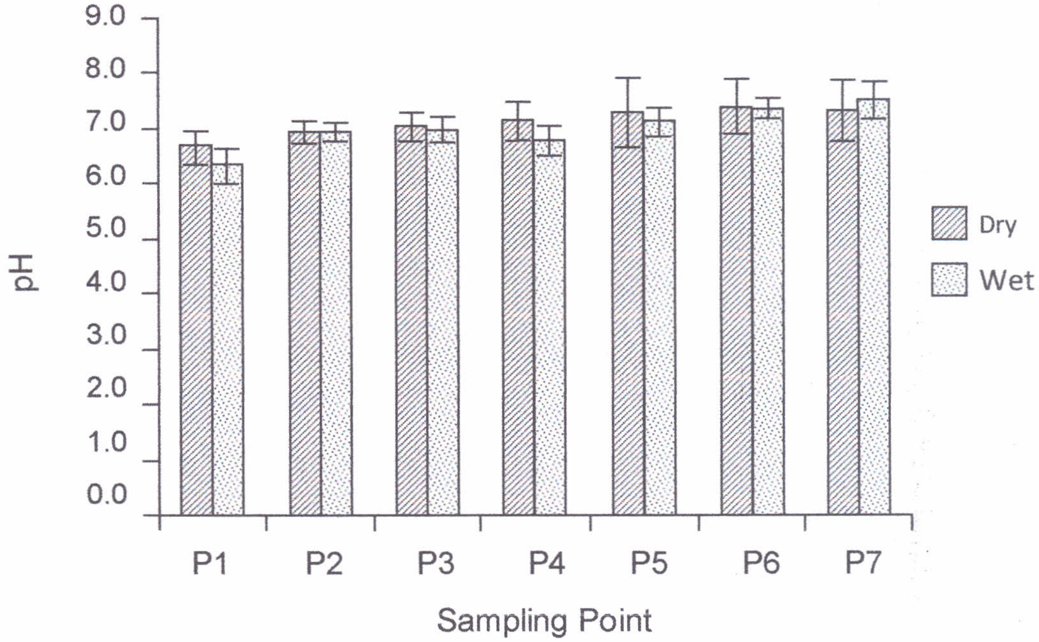

Figure 5.1: pH levels in surface water

Phosphorus concentration in surface water

Available phosphorus (PO_4) levels in water was significantly ($p<0.05$) different between the two seasons. Compared to the dry seasons, the wet seasons had considerably higher phosphorus levels at all sampling points (Figure 5.2). Phosphorus levels were lowest 0.3±0.2mg/l at sampling point 7 and highest (0.6 ±0.2mg/l) at sampling Point 1 during the dry seasons while sampling points 4 and 7 recorded the lowest (0.5±0.2mg/l) and highest (0.9 ±0.3mg/l) levels during the wet seasons respectively. The overall mean phosphorus concentrations for the dry and wet season were 0.5±0.2mg/L and 0.7±0.2mg/L respectively.

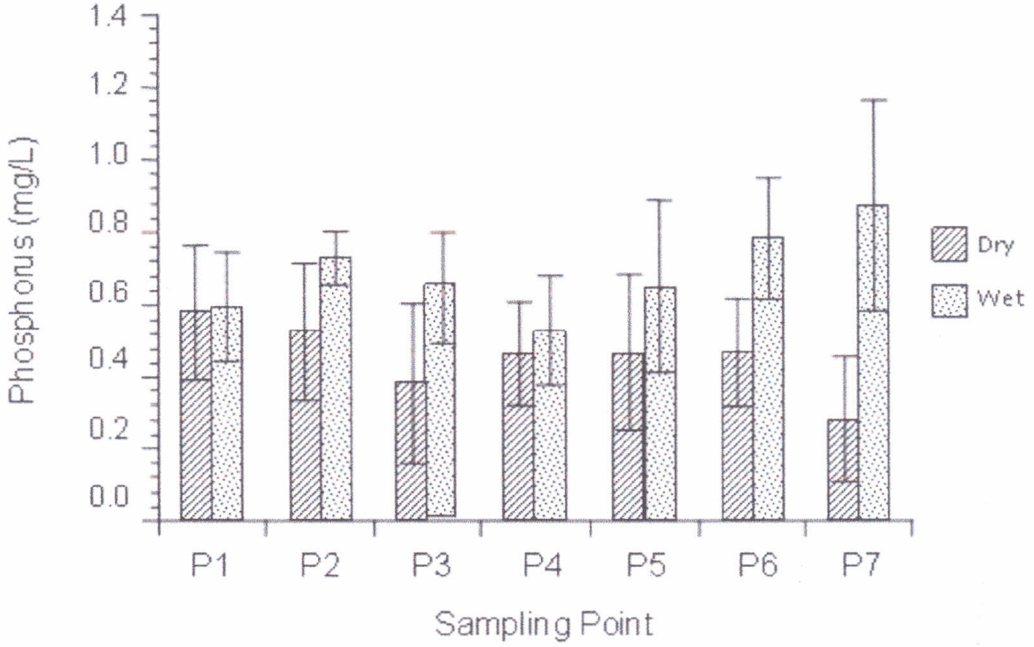

Figure 5.2: Phosphate (PO_4) content in surface water

Iron concentration in surface water

Iron concentration in surface water was significantly ($p<0.05$) different between the two seasons in that during the dry season only trace levels of Fe were recorded (Figure 5.3). However, during the wet seasons, significantly ($p<0.05$) higher iron content were recorded in waters with values ranging from 0.6±0.4mg/L to 5.4±4.9mg/L at Sampling Points 5 and 1 respectively. The overall mean values for the dry and wet season were 0.0±0.0mg/L and 2.5±0.8mg/L respectively.

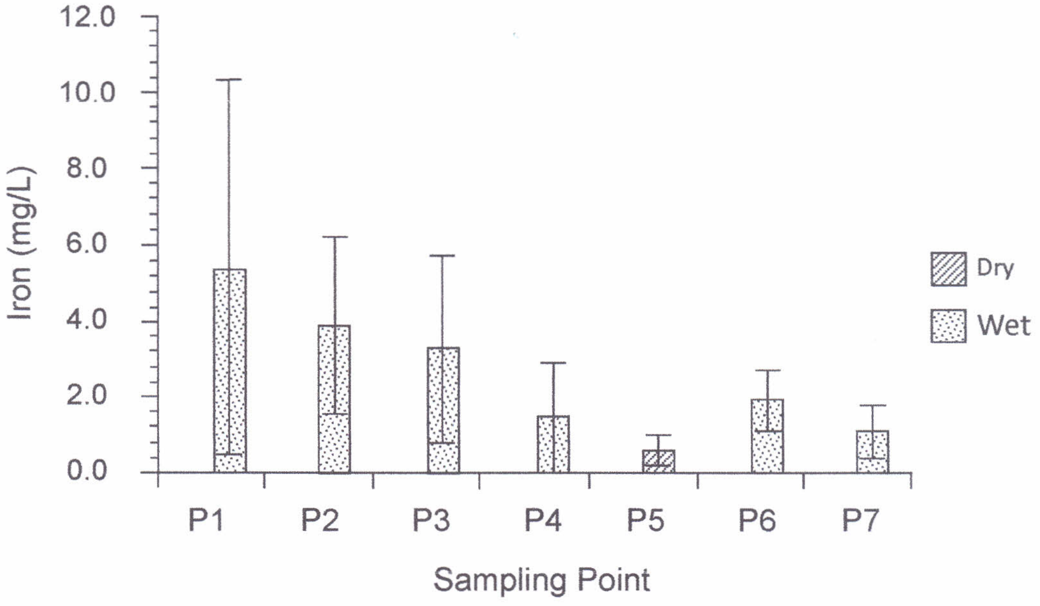

Figure 5.3: Iron (Fe) content in surface water

Sulphur concentration in surface water

Levels of sulphur (in form of SO_4) in surface waters was not significantly ($p>0.05$) different between the two seasons although the wet season generally registered higher sulphur levels compared to the dry season (Figure 5.4). There was a significant ($P<0.05$) difference in sulphur levels across sampling points. Sampling Point 7 situated at the furthest downstream recorded the highest values in the dry seasons (14.4±8.3mg/L). The concentration of sulphur (SO_4) ranged from 2.6±1.6mg/L to 14.4±8.3mg/L and 3.9±2.3mg/L to 8.5±3.4mg/L for the dry and wet seasons respectively (Figure 5.4). The overall mean concentrations were 6.3±2.6mg/L and 6.0±3.2mg/L for the dry and wet season respectively.

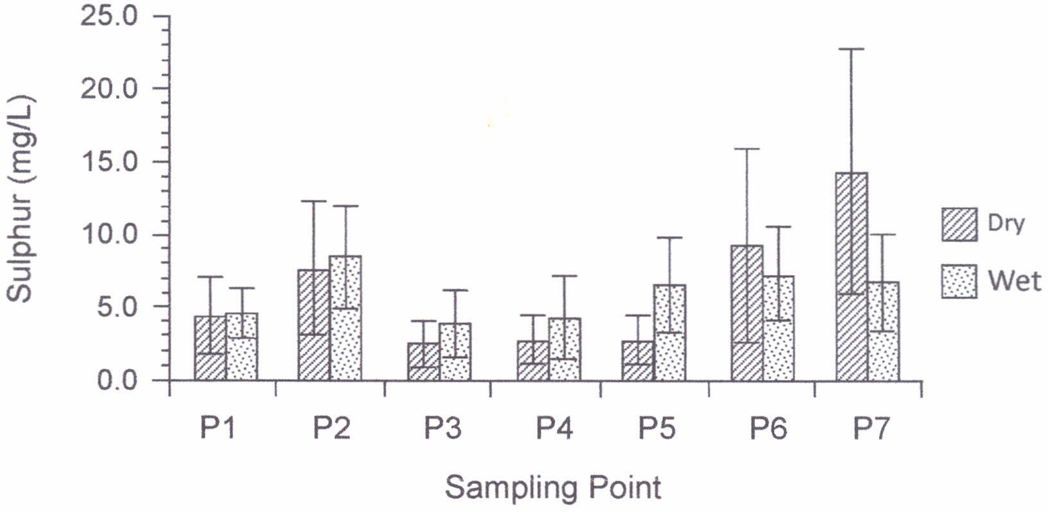

Figure 5.4: Sulphate (SO_4) content in surface water

Potassium concentration in surface water

Potassium levels were not significantly ($p>0.05$) different between the wet and dry seasons (Figure 5.5). However, the wet season registered generally higher concentrations with values varying from 1.7±0.3mg/L and 6.9±4.7mg/L at Sampling Points 1 and 6 (overall mean of 2.1±0.9mg/L) compared to dry season that ranged from 1.8±0.8mg/L to 2.4±0.8mg/L at Sampling Points 3 and 5 (overall mean of 5.1±3.0mg/L) respectively (Figure 5.5).

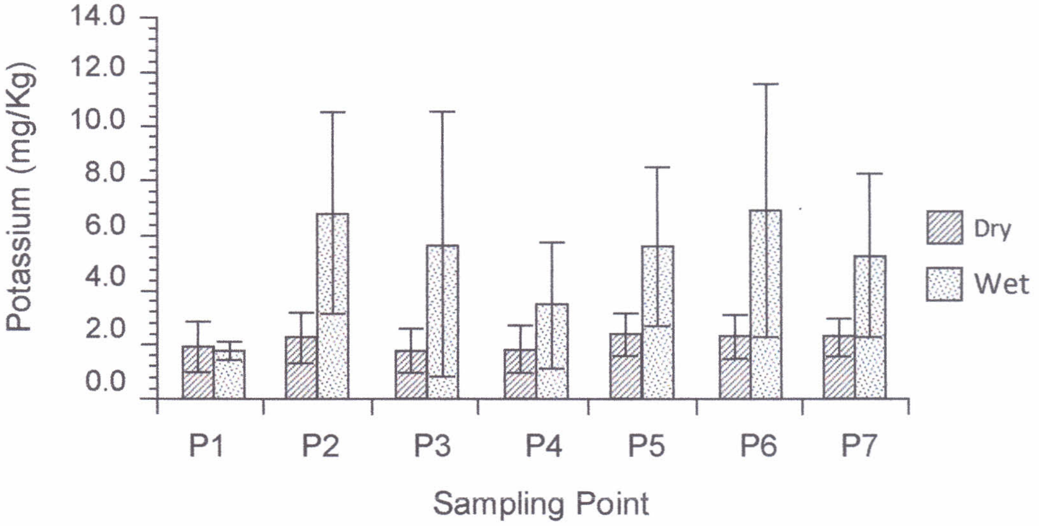

Figure 5.5: Potassium content in surface water

Calcium concentration in surface water

Levels of calcium differed significantly ($p<0.05$) between the two seasons. Calcium levels were significantly ($p<0.05$) higher in the dry season compared to the wet season at all sampling points. Values during the dry season varied from 7.6±3.0mg/L to 11.7±4.4mg/L at Sampling Points 3 and 2 with (overall mean of 9.2±3.3mg/L) while the wet season concentration varied from 4.0±2.0mg/L to 7.4±1.7mg/L at Sampling Points 1 and 5 respectively (overall mean of 5.7±1.5mg/L) (Figure 5.6).

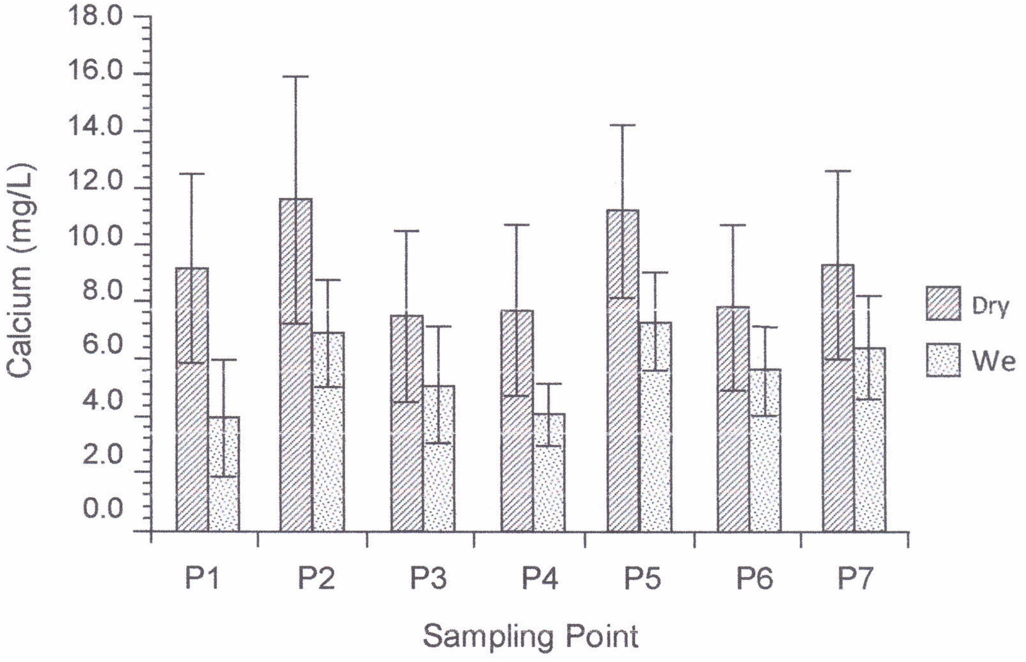

Figure 5.6: Calcium content in surface water

Magnesium concentration in surface water

Magnesium levels differed significantly (p<0.05) between the two seasons with highest values recorded during the dry seasons (Figure 5.7). As was the case with calcium concentration in water, magnesium concentration was found to be higher in the dry seasons than during the wet seasons (Figure 5.7*)*. Levels of Mg in the dry seasons ranged from 1.9±1.5mg/L to 4.7±3.7mg/L at Sampling Points 3 and 7 whereas the wet seasons ranged from 0.8±0.2mg/L to 2.3±0.4mg/L at Sampling Points 1 and 2 respectively. The overall mean values were 3.7±3.4mg/L and 1.4±0.4mg/L for the dry and wet seasons respectively.

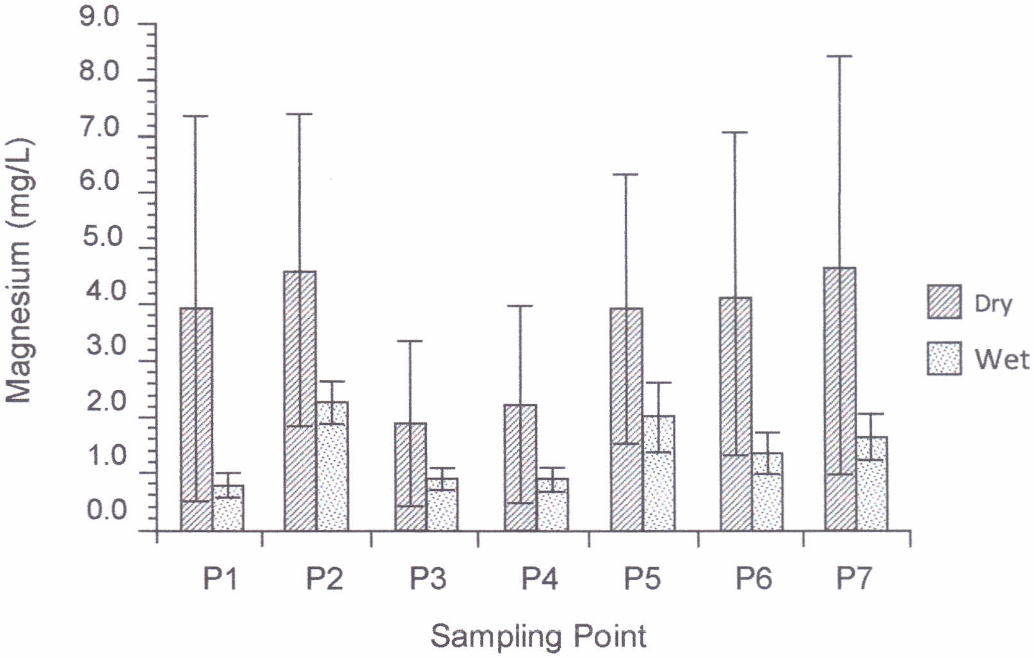

Figure 5.7: Magnesium (Mg) content in surface water

Copper concentration in surface water

Copper was recorded in all sampling points during the wet season except for sampling point 4. However, during the dry season, copper was only found in traces in points 1 and 4 (overall mean of 0.001±0.001mg/l) (Figure 5.8). Among the nutrients investigated in this study, copper recorded the least concentrations in surface water for the two seasons.

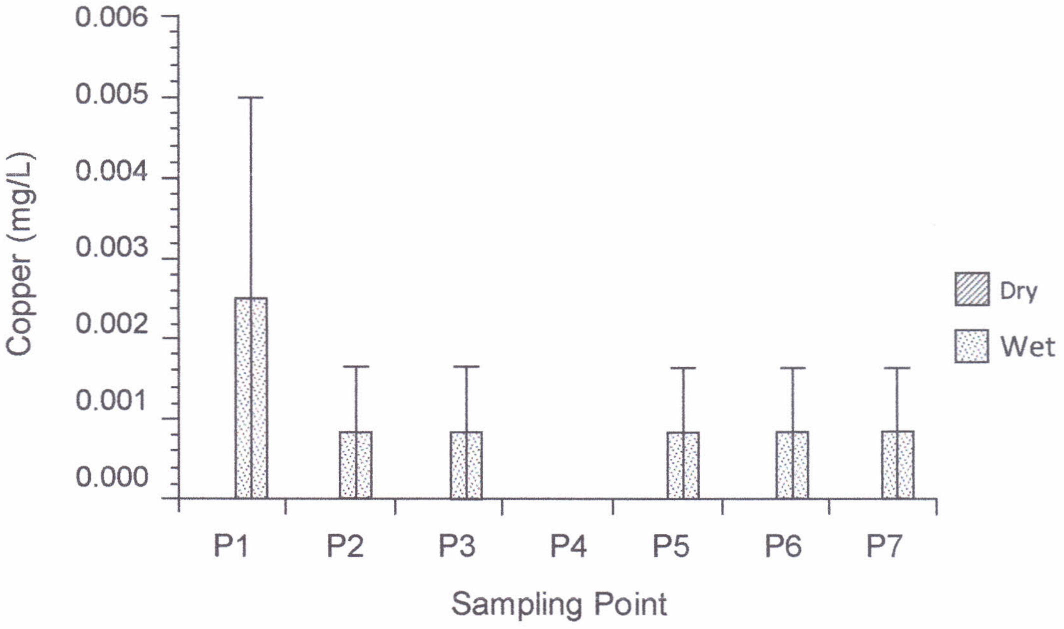

Figure 5.8: Copper (Cu) content in surface water

Manganese concentration in surface water

Results show that although manganese levels in the swamp water were not significantly ($p>0.05$) different between the dry and wet seasons however, the wet seasons registered generally higher manganese concentrations compared to the dry seasons (Figure 5.9). As was in the case of copper, the dry seasons recorded no (0.0mg/L) manganese content at all sampling points. However, the wet seasons registered amounts ranging from 0.1±0.1mg/L to 7.6±6.8mg/L at Sampling Points 7 and 1 respectively. Sampling Point 1 registered notably higher manganese levels (7.6±6.8mg/L) in the wet season compared to the other sampling points (Figure 5.9), with an overall mean value 1.3±0.6mg/L.

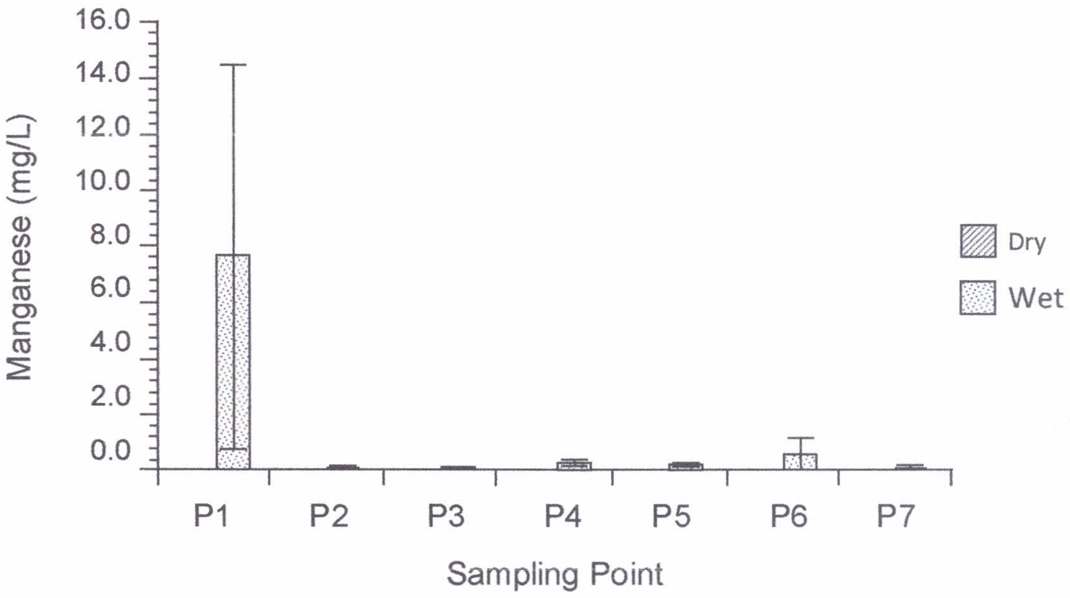

Figure 5.9: Manganese (Mn) content in surface water

Zinc concentration in surface water

Zinc concentration in water was not significantly ($p>0.05$) different between the wet and dry seasons. However, generally higher zinc levels were recorded during wet seasons compared to dry seasons (Figure 5.10). During the dry seasons, no zinc was registered at all sampling points. During the wet seasons trace amounts were recorded at Sampling Points 1, 2, and 3 that ranged from (0.01±0.01mg/L) to (0.03±0.03mg/L). The other sampling points recorded no zinc in the water during the wet season. The overall mean value for the wet season was 0.01±0.01mg/L.

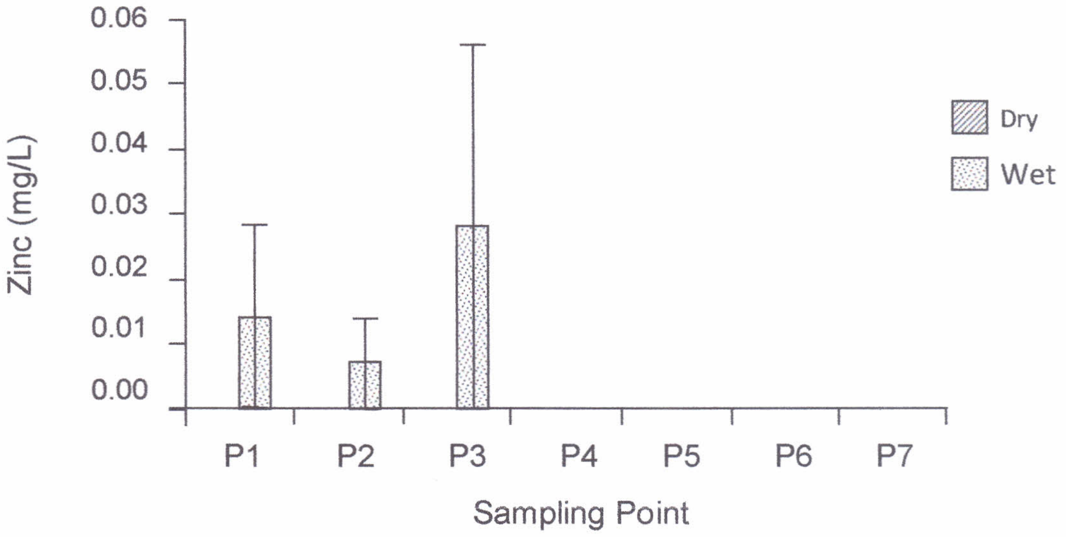

Figure 5.10: Zinc (Zn) content in surface water

5.4.2 Nutrients concentrations in Saiwa swamp soil sediments

pH levels in soil sediments

pH for soil sediments was found be significantly ($p<0.05$) different between the dry and wet seasons. Swamp soil sediments were slightly acidic (pH<7) during the dry and wet seasons (Figure 5.11). The soil sediments during the wet seasons were, however, significantly ($p<0.05$) more acidic than during the dry seasons. Results show that Sampling Points 1 and 7 recorded the lowest and the highest pH values for both the dry and wet seasons respectively (Figure 5.11). The mean pH values for the two seasons were pH 5.0±0.3 and pH 4.7±0.2 for dry and wet seasons respectively. pH during the dry seasons varied from 4.4±0.4 *to* 5.7±0.4 at Sampling Points 1 and 7 respectively. pH during the wet seasons varied significantly ($p<0.05$) from 3.9±0.1 to pH 5.3±0.1 at Sampling Points 1 and 7 respectively.

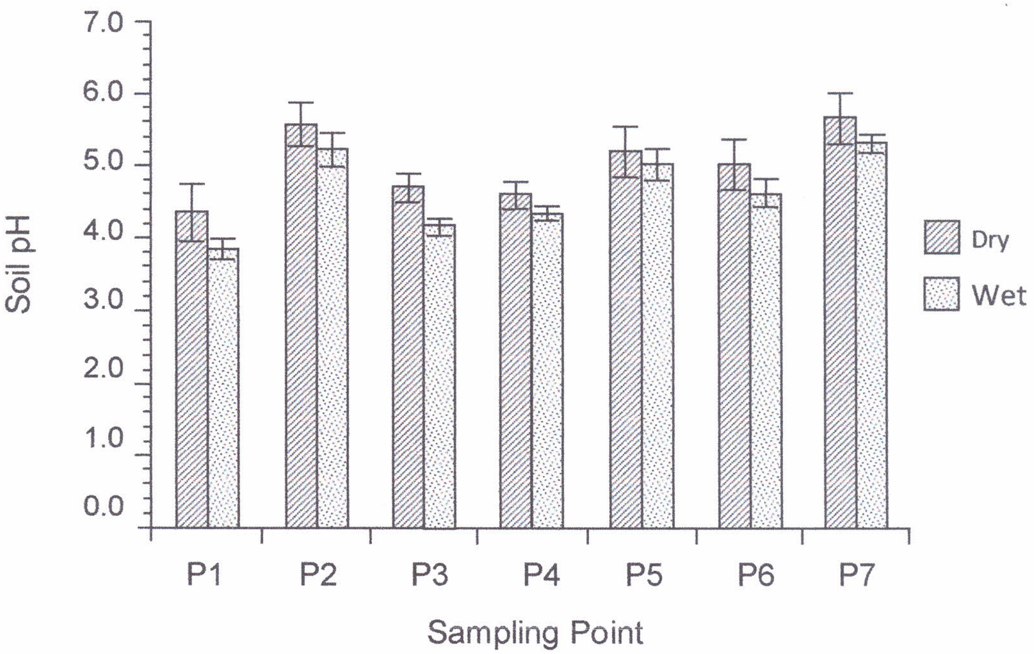

Figure 5.11: pH of soil sediments

Phosphorus concentration in soils

Available phosphorus (as phosphate) in the swamp soil sediments was not significantly (p>0.05) different between the dry and wet seasons. However, the wet seasons recorded generally higher phosphorus content compared to the dry seasons with values varying from 10.0±1.9mg/Kg to 78.2±6.0mg/Kg and 11.4±5.2mg/Kg to 66.7±5.2mg/Kg respectively (Figure 5.12). Results show that Sampling Points 1, 6 and 7 recorded higher phosphorus content in the dry season compared to the wet season although this difference was not significant (p>0.05). Sampling Point 5 registered remarkably higher phosphorus content than the other Sampling Points in both seasons (Figure 5.12). The overall mean phosphorus concentrations were 32.2±9.2mg/Kg and 37.3±3.5mg/Kg for the dry and wet seasons respectively.

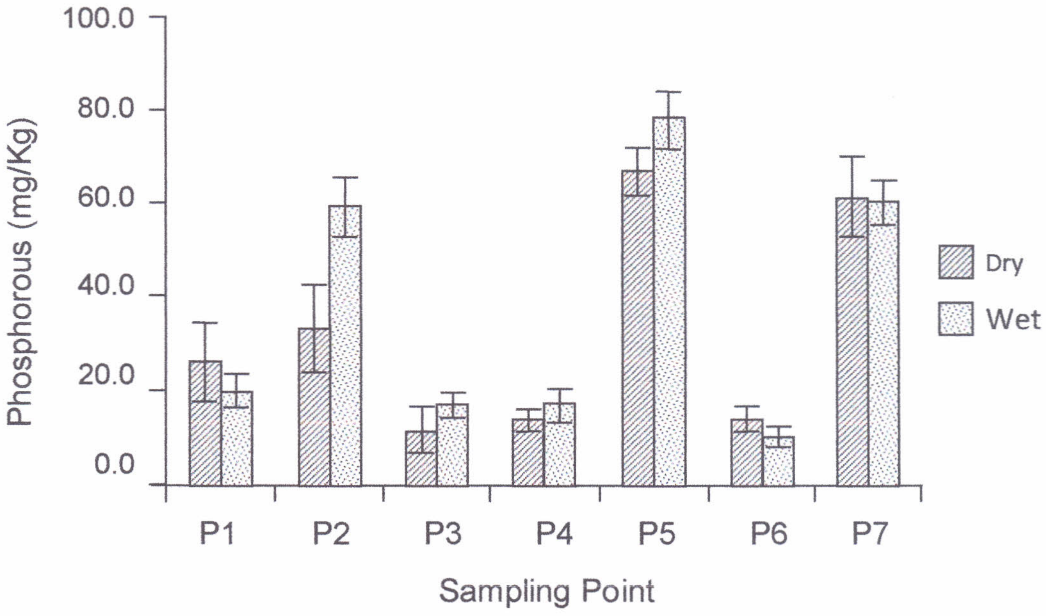

Figure 5.12: Phosphate (PO_4) content of soil sediments

Iron concentration in soils

Iron levels in the soil sediments were significantly ($p<0.05$) different between the dry and wet seasons. Significantly ($p<0.05$) higher levels of iron were recorded during the dry seasons (ranged from 1387.2±178.1mg/Kg to 12120.1±1892.3mg/Kg) than during the wet seasons which ranged from 1069.7±489.9mg/Kg to 5368.4±1670.0mg/Kg (Figure 5.13). The mean values for the two seasons were 5445.6±1781.4mg/Kg and 3104.4±1097.4mg/Kg respectively. Sampling Point 6 showed exceptionally high iron content (12120.1±1892.3mg/Kg) in the dry season compared to the other sampling points during the dry and wet seasons (Figure 5.13).

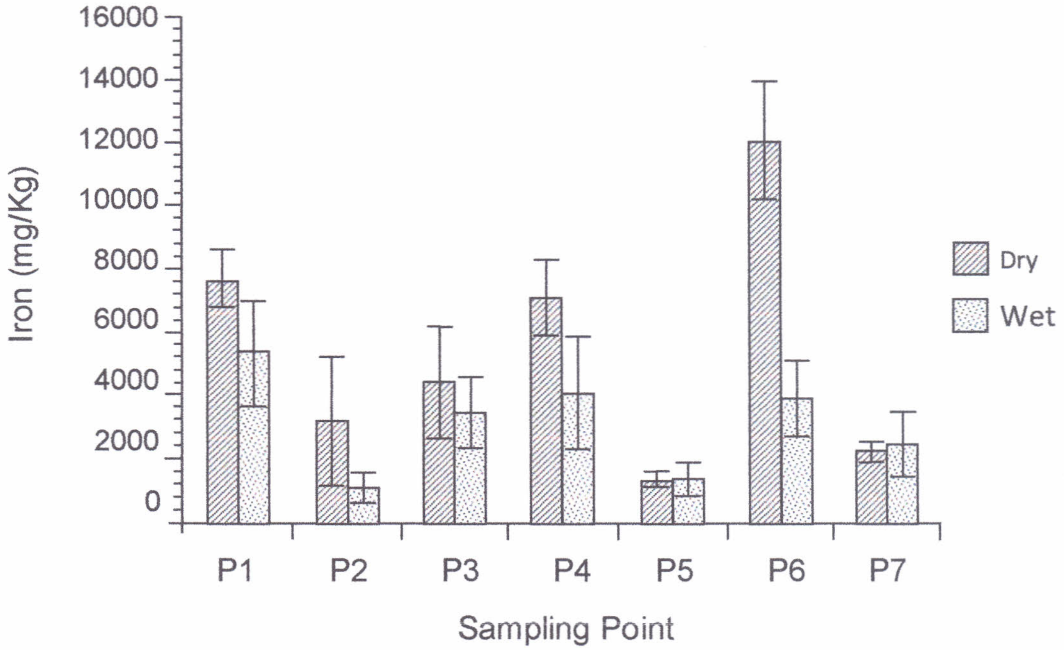

Figure 5.13: Iron content of soil sediments

Sulphur concentration in soils

There were highly significantly ($p<0.001$) sulphur (in form of SO_4) levels in the swamp soil sediments different between the two seasons. The dry seasons recorded significantly ($p<0.001$) lower sulphur (SO_4) content than the wet seasons with values ranging from 11.0±1.8mg/Kg to 47.1±16.7mg/Kg for the dry seasons and 61.5±17.4mg/Kg to 237.0±89.0mg/Kg for the wet seasons respectively (Figure 5.14). Sampling Point 6 showed exceptionally higher levels of sulphur (SO_4) (237.0±89.0mg/Kg) during the wet seasons compared to the other sampling points (Figure 5.14). The overall mean content of sulphur (SO_4) during the dry and wet seasons was 25.3±5.7mg/Kg and 133.8±29.2mg/Kg respectively.

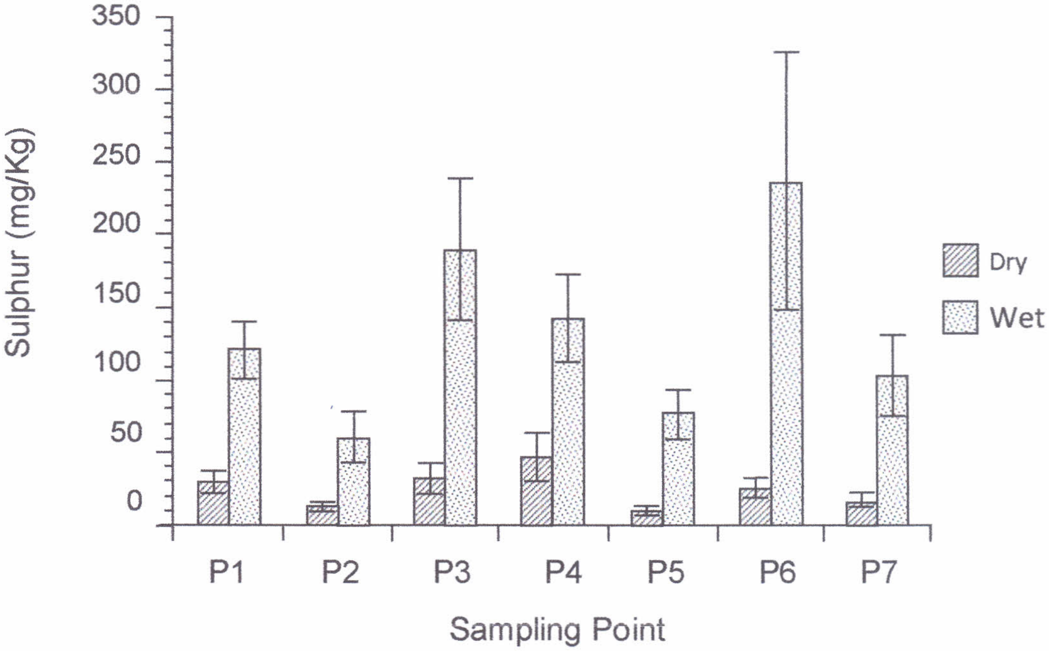

Figure 5.14: Sulphur content of soil sediments

Potassium concentration in soils

Potassium levels in the swamp soil sediments were significantly ($p<0.001$) higher during the wet seasons than during the dry seasons (Figure 5.15). The wet season registered significantly ($p<0.001$) higher potassium concentrations varying from 161.7±70.7mg/Kg to 319.0±90.2mg/Kg at Sampling Points 4 and 5 respectively compared to the dry season where values ranged from 61.2±11.5mg/Kg to 163.3±17.1mg/Kg at Sampling Points 2 and 6 respectively (Figure 5.15). Sampling Point 4 showed notably higher potassium content (319.0±90.2mg/Kg) in the wet season compared to the other sampling points in both dry and wet seasons (Figure 5.15). The overall mean potassium contents for the dry and wet season were 106.9±23.0mg/Kg and 222.9±83.2mg/Kg respectively.

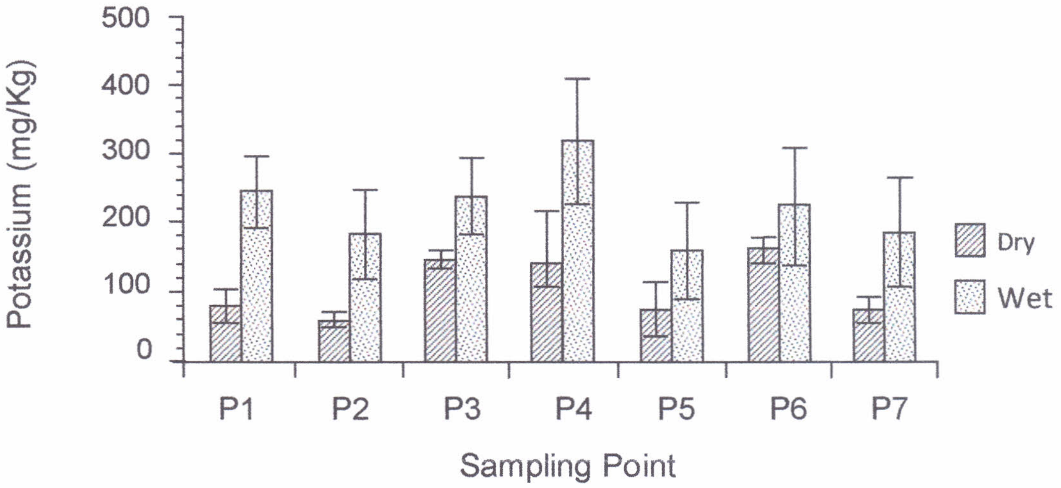

Figure 5.15: Potassium content of soil sediments

Calcium content in soils

Calcium levels were not significantly (p>0.05) different between the dry and wet seasons, although the wet seasons recorded higher calcium concentrations than the dry season except for Sampling Points 3, 5 and 7 (Figure 5.16). Calcium levels during the dry seasons varied from 1144.1±184.0mg/Kg to 2398.3±203.8mg/Kg at Sampling Point 2 and 3 while it varied from 1334.4±241.7mg/Kg to 2439.9±455.2mg/Kg for Sampling Points 2 and 4 during the wet season respectively. Figure 5.16 shows that Sampling Points 2 listed the lowest calcium content in the soil sediments during both the wet and dry seasons.

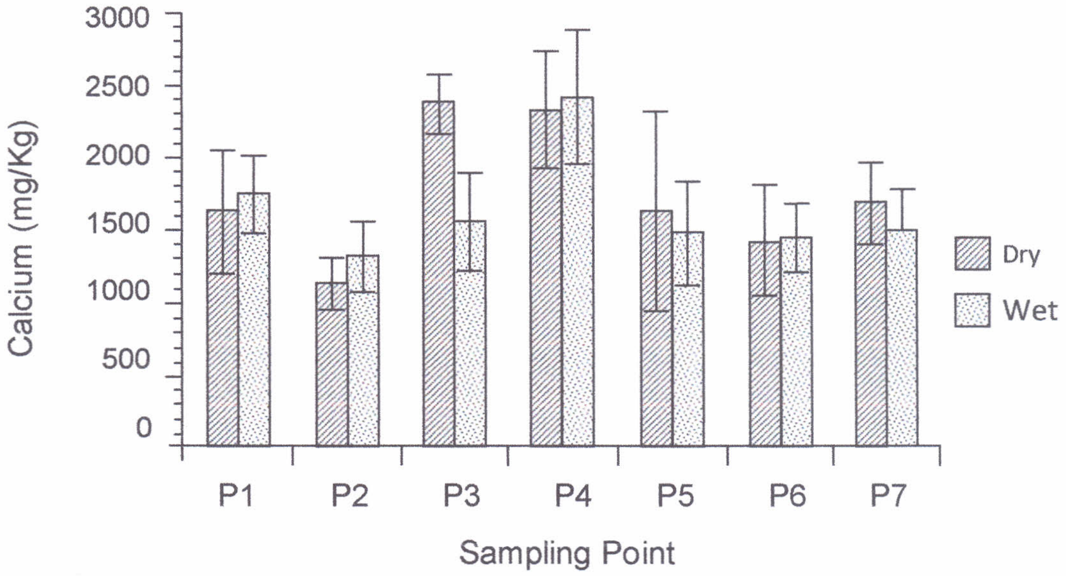

Figure 5.16: Calcium content of soil sediments

Magnesium content in soils

The levels of magnesium in soil sediments were significantly ($p<0.001$) higher during the wet seasons than those of the dry seasons. The values varied from 106.7±34.3mg/Kg to 352.8±85.3mg/Kg (overall of mean of 237.6±16.0mg/Kg) and 307.3±38.0mg/Kg to 608.6±94.6mg/Kg (overall mean of 413.3±71.5mg/Kg) during the dry and wet seasons respectively (Figure 5.17). Sampling Point 4 recorded the highest magnesium concentration in both seasons which was significantly different from the other Sampling Points (Figure 5.17).

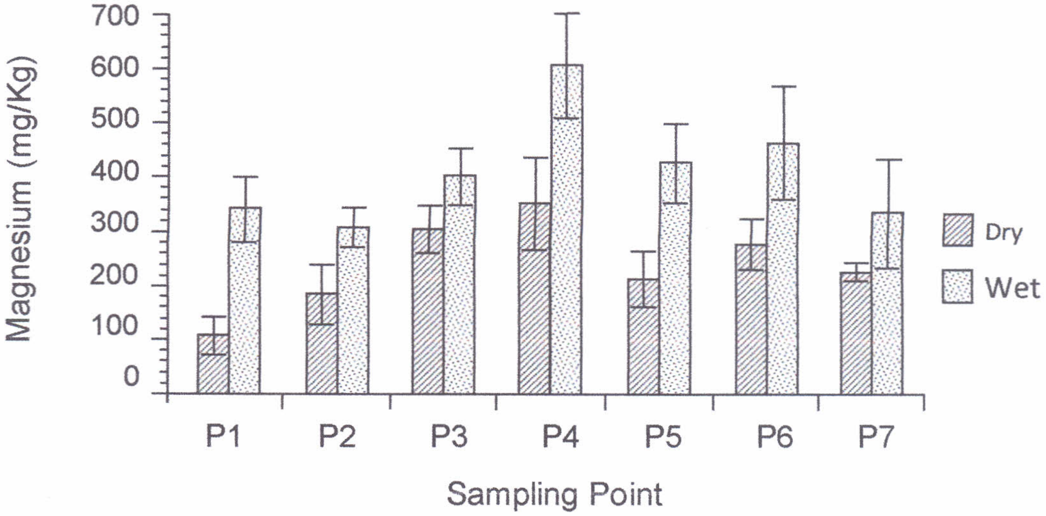

Figure 5.17: Magnesium content of soil sediments

Copper concentrations in soil sediments

Levels of copper in soil sediments was not significantly (p>0.05) different between the dry and wet seasons. However, the wet season exhibited generally higher copper concentration compared to the dry seasons except at Sampling Points 1, 5 and 7. The values ranged from 1.6±0.8mg/Kg to 6.7±0.5mg/Kg (overall mean of 4.6±1.2mg/Kg) and 2.4±0.9mg/Kg to 7.0±0.8mg/Kg (overall mean of 4.3±1.0mg/Kg) for the dry and wet seasons respectively (Figure 5.18). Sampling Point 1 recorded the highest copper level (7.0±0.8mg/Kg) in the wet season while it highest (at 6.7±0.5mg/Kg) at Sampling Point 4 in the dry season. Among the nutrients investigated in this study, copper was found to have the least concentrations in both the dry and wet season mainly occurring in trace amounts.

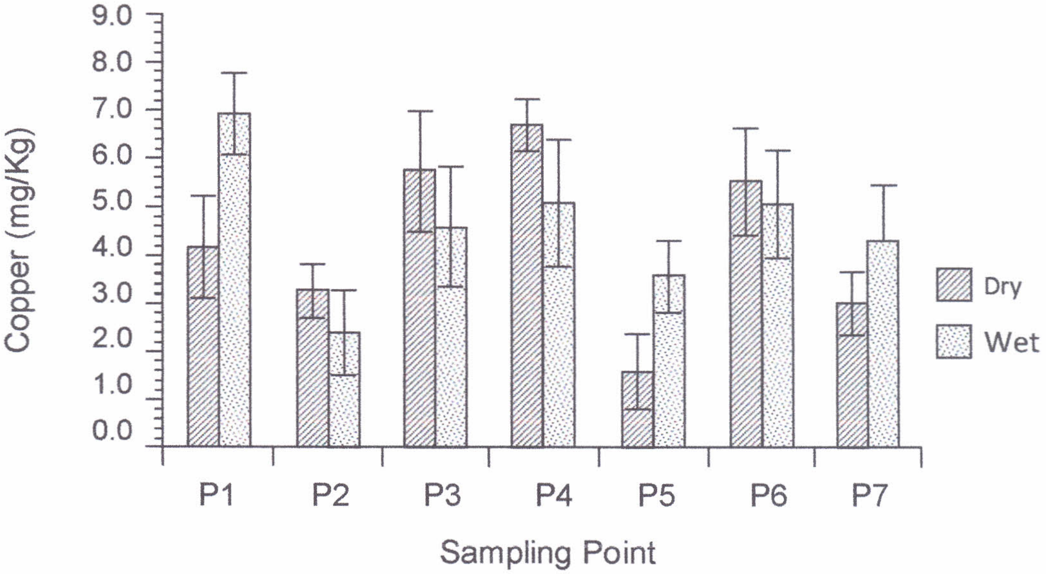

Figure 5.18: Copper content of soil sediments

Manganese concentrations in soils

Manganese levels in soil sediments did not differ significantly (p>0.05) between the two seasons. However, the wet seasons recorded higher manganese levels at many sampling points compared to the dry season except at Sampling Points 1, 5 and 7 (Figure 5.19). Levels of manganese during the dry seasons varied from 259.6±81.6mg/Kg to 1754.1±164.9m/Kg at Sampling Points 5 and 6 while levels for wet season varied from 483.8±188.9mg/Kg to 2063.7±463.1mg/Kg at Sampling Points 2 and 6 respectively. Sampling Point 6 exhibited conspicuously higher manganese concentrations in both dry and wet seasons compared to the other sampling points (Figure 5.19). The overall mean manganese content for the dry and wet seasons was 772.7±108.1mg/Kg and 914.3±216.5mg/Kg respectively.

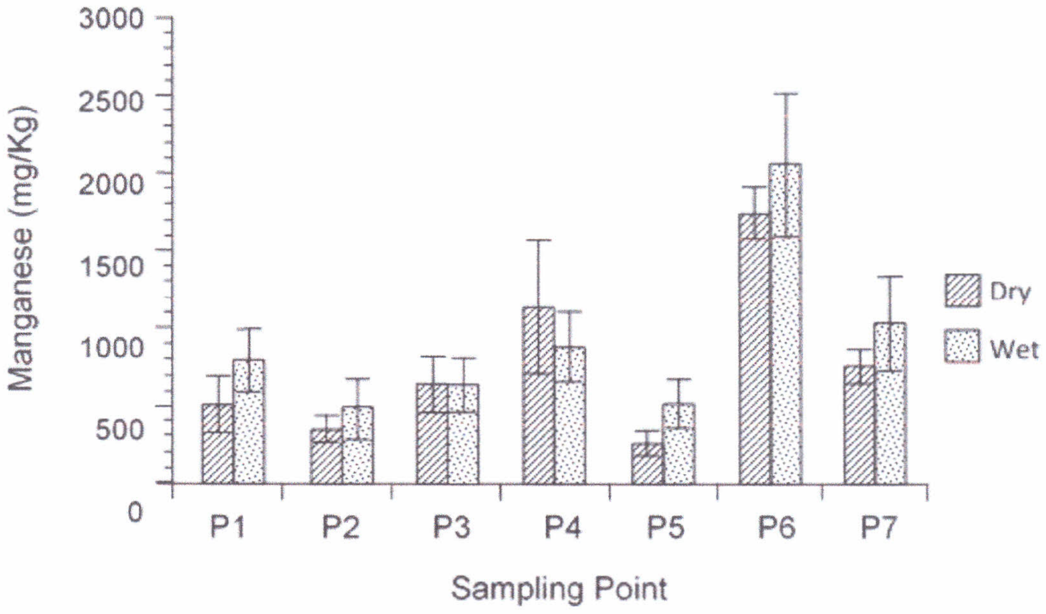

Figure 5.19: Manganese content of soil sediments

Zinc concentrations in soils

Zinc levels in soil sediments were not significantly (p>0.05) higher in the wet than in the dry seasons. The wet season showing higher zinc levels at all sampling points compared to the dry season (Figure 5.20). Dry season levels of zinc ranged from 1.7±0.3mg/Kg to 28.4±7.5mg/Kg at Sampling Points 5 and 1 while wet season levels varied from 46.0±27.9mg/Kg to 313.0±294.0mg/Kg at Sampling Points 3 and 6 respectively. Sampling Point 6 showed exceptionally high zinc concentration (313.0±294.0mg/Kg) in the wet season compared to the other sampling points although the difference was not highly significant (p>0.05). The overall mean zinc contents for the dry and wet season were 9.3±0.9mg/Kg and 123.0±92.4mg/Kg respectively.

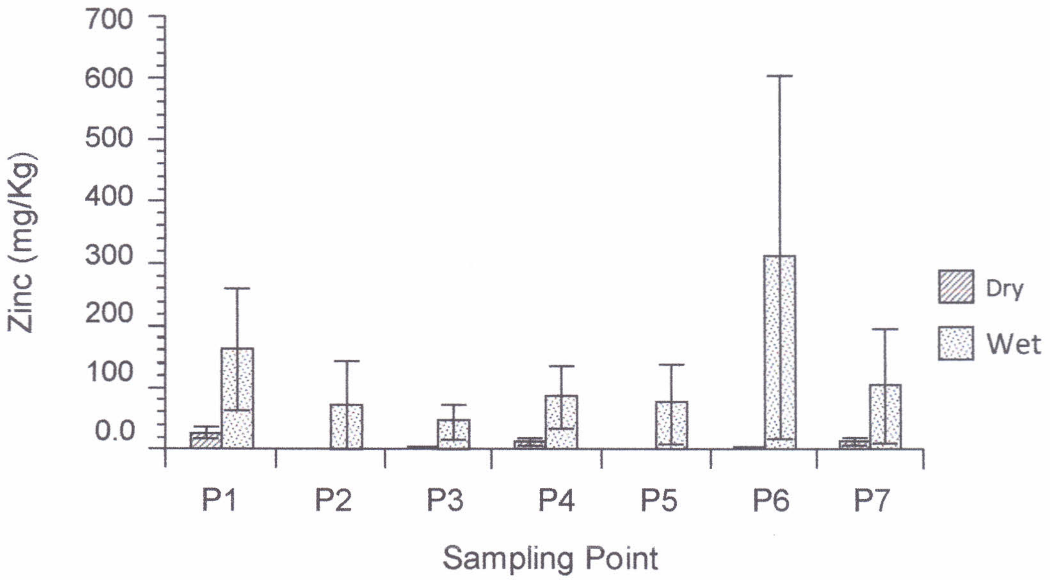

Figure 5.20: Zinc content of soil sediments

5.5. Discussion

pH is a measure of the acidity or alkalinity and represents the hydrogen ion (H^+) content in a medium such as water (Katimon *et al.*, 2004). In biological systems, pH of water determines the solubility and biological availability to organisms of chemical constituents such as phosphorous, potassium, sulphur and heavy metals such as copper, zinc and manganese (Gaudet, 1979). It also determines the type of aquatic life of a water body. Saiwa swamp waters can be categorized as nearly neutral during both dry and wet seasons with mean pH values of 7.1 and 7. 0 respectively. Overall, during the wet seasons, water pH was comparatively lower than during dry seasons, suggesting that the swamp gets more inundated with acidic substances from surface runoff emanating from non-point sources during the wet seasons (Katimon *et al.*, 2004). The swamp soils were found to be more acidic with mean pH of 5.0 and 4.7 for dry and wet seasons respectively. This is in line with findings of Katimon *et al.* (2004) who reported that many tropical soils located along rivers are potentially acidic. Soil acidic conditions during the wet seasons could possibly be due to leaching of acidic substances into the water body from the swamp environments which later accumulate onto sediments due to the filtering effect of the swamp biota. Organic acids, especially humic ($C_{187}H_{186}O_{89}N_9S_1$) and fluvic ($C_{135}H_{182}O_{95}N_5S$) acids, are also produced during organic decomposition in these environments (Katimon *et al.*, 2004).

Highest phosphorus levels were recorded during the wet seasons compared to the dry seasons for both the waters and the soils. These seasonal differences could indicate higher phosphate fertilizer leakages into the swamp waters from the surrounding agricultural farms. This could also explain the observed higher phosphorus content in swamp soils compared to the surface water noted in this study. It has been reported by Muthuri and Jones (1997) that for most aquatic ecosystems, phosphorus is generally the limiting element for plant growth and therefore its availability from the farms could cause eutrophication of the water bodies.

Contrary to the case of waters, soils registered higher iron (Fe) content during the dry seasons compared to the wet seasons. This could be explained by the weathering and dissolving and eventual leaching of solutes of the ferrasol and fluvisol rocks that dominate in the study area. The exceptionally high soil iron content (12120.1 mg/kg) recorded in dry season at Sampling Point 6, which is the entry point into the swamp of River Kipsaina, could be attributed to the agrochemicals from the many horticultural activities from surrounding farms found on the banks of River Kipsaina. The banks of this river have been converted to small scale plots and farms where crops such as tomatoes and kales are grown.

Comparison, revealed that the wet seasons had the highest sulphur levels than the dry seasons, probably due to greater discharge of sulphur compounds into the water body during the wet season from the surrounding swamp environments. Sulphur levels (10-237 mg/L) found in the soil sediments, however, fell within the ranges reported in other tropical swamp sediments (Gaudet and Muthuri, 1981). However, soil sediments contained more sulphur compared to surface waters and this could be attributed to adsorption of sulphur compounds onto soil sediments. In addition, sampling point 6 recorded exceptionally high levels of sulphur (237.0 mg/kg) during the wet seasons compared to the other sampling points and times. This was perhaps due to deposition of sulphates from the environments as a result of the horticultural activities from surrounding farms found on the banks of River Kipsaina.

Potassium registered highest levels during the wet seasons than the dry seasons for both the waters and soils. Potassium is an alkali metal that forms highly soluble salts which are easily leached into the water. The point source of these metals could be linked to the excess potassium fertilizers (with NPK component) used in the surrounding farms. If fertilizer application on crops exceeds their requirements, excess fertilizer is drained into the water (Divya and Belagali, 2012). This was particularly observed at points 1 and 6, which are entry points of rivers Saiwa and Kipsaina to the swamp environment. The general catchment of the two rivers is the Saiwa catchment with extensive farms ranging from Kapenguria to Mt. Elgon. Sampling Point 1 showed notably high potassium content (319.0 mg/kg) in the wet season compared to the other sampling points. Since sampling point 1 was the surface water entry point to the swamp, less or no filtration of nutrients took place at this point of entry. During both seasons, potassium levels were highest in the sediments than surface waters at all sampling points probably due to deposition and the purification effect of the swamp.

In contrast to most of the other nutrients, calcium levels in surface waters were significantly ($p = 0.05$) higher during dry seasons compared to wet seasons at all sampling points. This was presumably due to decreased water volume in the swamp during the dry season, resulting into higher calcium concentration. Calcium is one of the alkaline earth metals that are widely distributed in the earth's crust and present in almost all waters (Garg, 1987). It occurs in radicals of carbonates and bicarbonates in waters of high salinity, although calcium chloride and nitrates can also be found (Garg, 1987). Sampling point 4 recorded the lowest content of calcium in the soils in both seasons unlike surface waters. This could be explained by the location of Sampling Point 4 in the middle of River Saiwa that experiences fast running waters, hence resulting in little deposition and uptake of the calcium salts by soils and vegetation.

Similarly, magnesium levels were highest during dry seasons than wet seasons, possibly as a result of decreased water volume in the swamp during dry seasons resulting in concentration of the element after evapotranspiration takes place. This is in line with study by Ndubi *et al.* (2015) in similar environments in Kenya. Magnesium resembles calcium in most of its chemical properties although its solubility is about ten times higher (Garg, 1987). Magnesium forms highly soluble salts which contribute to both carbonate and non-carbonate water hardness but to a lesser extent than the calcium component. The high values recorded for calcium and magnesium during the dry seasons was possibly due to decreased volume of water in the swamp caused by less river flow and increased evapotranspiration in the swamp. The prevailing high temperatures in the area during dry seasons could increase the concentration of calcium and magnesium salts through evapotranspiration (Medudhula *et al.*, 2012). The low values of 1.4 mg/L and 5.7mg/L, recorded in the wet seasons for magnesium and calcium respectively, could be due to dilution by the increased inflow of waters.

Traces of copper were recorded in sediments but not in the surface waters during both dry and wet seasons. Among all the elements investigated, copper recorded the least amounts. These results are similar to those of Mwaniki *et al.* (2013). Copper is a heavy metal that is associated with pollution and was highest at sampling point 6 during wet seasons suggesting pesticide or fungicides source from surrounding agricultural farms.

During the dry seasons lower trace amounts of manganese were recorded in water compared to the wet seasons. Like for iron, copper and zinc recorded highest amounts during wet seasons. This could be due to discharge of these elements into the waters during the wet season through seepage and leaching from the swamp environments as opposed to the dry season. Manganese pollution is linked to fossil fuels and oils from automobile exhausts (Gaudet, 1979) and in this case it could have come from tractors that are used to prepare land prior to crop cultivation in the Saiwa catchment. Sampling Point 1 registered conspicuously high manganese levels (7.6 mg/L) in surface water during the wet seasons compared to the other sampling points possibly due to this element being dissolved from the surrounding farms before water flows into the swamp. On the other hand, Sampling Point 6 exhibited conspicuously higher levels of manganese sediment concentration during both seasons compared to the other sampling points.

As noted earlier, River Kipsaina flows into Sampling Point 6, and drains from many small horticultural farms that are found on its banks. Therefore, manganese could be originating from agrochemicals (especially pesticides) used even during the dry seasons for controlling pests and crop diseases. As Sampling Point 6 was closer to Sampling Point 7, it perhaps influenced the high values at Sampling Point 7 as water had less residence time within the swamp for mopping up by the swamp.

Levels of manganese during the dry seasons were within the levels recommended by WHO guidelines of 0.1 mg/L for drinking water but were above this value during the wet seasons. This makes the swamp water unsuitable for domestic purposes, hence the need to conserve the wetlands for filtration of manganese before it is discharged to the rivers and subsequent use of its waters. Exit sampling point 7 recorded low values of manganese compared to the other sampling points, showing the critical function of cleaning up of such elements from polluted waters by wetlands. While the wet season registered very low trace amounts of zinc in both waters and soils, especially from sampling points 1, 2 and 3, no traceable amounts of Zn were recorded during the dry seasons at all sampling points. This could be indicative of the purifying effect of the water by the wetland.

Many of the elements recorded higher levels during wet seasons as compared to the dry seasons in both water and soil sediments. In many rural areas where agricultural practices are common, sediments, nutrients and toxic chemicals enter wetlands, primarily by way of runoff (Raburu, 2003; Kithiia, 2006). Where the runoff drains freshly-ploughed fields, as is the case around Saiwa catchment area, it may carry a lot of pesticides and fertilizers applied on land during farming activities. This probably explains the observed higher concentrations of some elements in the wet season compared to the dry season in this study. Essentially, soil sediments recorded higher levels of mineral elements than in the surface water. Toxic chemicals reach surface waters in the same way as other elements, and can cause disease, death, or other problems upon exposure to plants and animals (including humans). Wetlands remove these pollutants by trapping the sediments, nutrients and toxic chemicals as they slow the velocity of waters and allow sediments to settle to the bottom where they are held in place (Garg, 1987). This demonstrates the vital role of wetlands in pollution control and the need to maintain and restore wetland vegetation along riparian zones. In general, this study found that swamps played this vital role of retention of chemicals and metal elements, especially during the dry season when water flow is low, slow and has longer residence times within the swamp to allow for filtration and mopping up of these chemicals and sediments.

CHAPTER 6: FLORISTIC LIST OF THE PLANTS IN THE SAIWA SWAMP NATIONAL PARK

6.1 Introduction

The Saiwa National Park contains some of the original indigenous vegetation types of the watershed area most of which have now been cleared for cultivation and settlements. Although literature shows that the vegetation of Saiwa was documented (Ogutu, 1996), it is not clear how the vegetation has been affected in the recent past. This chapter therefore, undertook to describe the current situation on vegetation of the Saiwa Park wetland since the type of plant species is critical for proper planning and for long term conservation of the Park and provision of sustainable ecosystem services to the surrounding communities.

6.2 Study Area

The Saiwa watershed, located about 400 km west of Nairobi. Saiwa Swamp is situated in a watershed that is experiencing increasing human populations and farming activities (especially for maize which is the staple food crop in Kenya) - agricultural practices that, if not checked, may cause severe ecological impacts). The vegetation in the park consists of three communities: gallery forest (39%), open grassland park is situated 25 km north-east of Kitale Town (01° 05' N, 35° 07' E), at an elevation of about 1860m asl. It is located at the confluence of rivers Saiwa, which originates from the Cherengany ranges (3371m asl) to the north, and river Kipsaina which originates from Mt. Elgon (4321m asl) to the west. The two rivers join to form river Sinyerere that flows into river Nzoia further downstream and drains into Lake Victoria (Ogutu, 1996).

6.3 Materials and Methods

6.3.1 Determination of the plant species present within the Saiwa Park

At each of the sampling points used for the soil sediments and water chemical analysis, voucher specimens of the plant species present were collected, pressed and taken to the University of Nairobi Herbarium for identification and preservation. A checklist of the plant species was then compiled. Data on the floristic list was collected during the wet and dry seasons in order to determine plant species present during these periods. The walk through method was preferred because unlike the random quadrat method where the plant species are only listed when they occur within a quadrat, the rare species are taken care of by the walk-through method (Rauenhorst, 2016).

6.4 Results

The list of species encountered in the study area are as contained in Tables 6.1, 6.2 and 6.3. It shows that the tree component consisted of fewer number of species when compared to the shrubs. Trees were found in the gallery forest surrounding the swamp. Shrubs were more common in the ecotone areas between the swamp and the gallery forest and in areas north of the Park. Grasses were commonly found in patches north of the Park and in a few areas within the swamp interspersed with sedges. Sedges dominated the swamp although in some areas elephant grass has completely taken over.

Table 6.1: List of tree species found in Saiwa swamp National Park

Tree Species	**Family**
Acacia abyssinica	*Leguminosae*
Acacia lahai	*Leguminosae*
Adenia gummifera	*Passifloraceae*
Albizia gummifera	*Leguminosae*
Bridelia micrantha	*Eurphobiaceae*
Celtis africana	*Ulmaceae*
Combretum mole	*Combretaceae*
Croton macrostachyus	*Eurphobiaceae*
Cussonia spicata	*Umbeliferae*
Dalbergia lactea	*Leguminosae*
Ficus sycomorus	*Moraceae*
Markhamia lutea	*Bignoniaceae*
Nuxia congesta	*Loganiaceae*
Podocarpus falcatus	*Podocarpaceae*
Polyscias fulva	*Araliaceae*
Prunus africana	*Rosaceae*
Pterolobium stellatum	*Leguminosae*
Schrebera alata	*Oleaceae*
Syzygium cordatum	*Myrtaceae*
Syzygium guineense	*Myrtaceae*
Warburgia ugandensis	*Canelliaceae*

Table 6.2: List of shrubs and herbs species found in Saiwa swamp National Park

Shrub/Herb	**Family**
Achyranthes aspera	*Amarantheceae*
Ageratina adonophora	*Compositae*
Ageratum conyzoides	*Compositae*
Allophylus abyssinica	*Sapindaceae*
Bersema abyssinica	*Sapindaceae*
Catha edulis	*Celastraceae*
Clerodendrum johnstonii	*Verbanacaeae*
Crossocephalum picrindifolium	*Compositae*
Cyphostemma kilimandscharica	*Vitaceae*
Dodonea angustifolia	*Sapindaceae*
Dombeya burgessiae	*Sterculiaceae*
Dovyalis macrocalyx	*Flacourticaceae*
Droguetia iners	*Ulticaeae*
Embelia schimperi	*Myrsinaceae*
Erythrococca bongesis	*Euphorbiaceae*
Euclea divinorum	*Ebenaceae*
Fagaropsis angolensis	*Rutaceae*
Galinsoga parvifolia	*Compositae*
Gouania longispicata	*Rhamnaceae*
Gunnera perpense	*Haloragaceae*
Halleria lucida	*Scrophulariaceae*
Hibiscus callyphyllus	*Malvaceae*
Hippocratea africana	*Celastraceae*
Hugrophila spiciformis	*Acanthaceae*
Hydrocotyle ranunculoides	*Umbelliferae*
Hypoestes forskahlii	*Acanthaceae*
Jasminium fluminense	*Oleaceae*
Justicia flava	*Acanthaceae*
Kalonchoe crenata	*Crassulaceae*
Keetia gueinzii	*Rubiaceae*
Landolfia buchananii	*Apocynaceae*
Lantana trifolia	*Verbanaceae*
Ludwigia stonifera	*Onagraceae*
Maytenus heterophylla	*Celastraceae*
Microglossa pyrifolia	*Compositae*
Ochna holstii	*Ochnaceae*
Oenanthes palustris	*Umbelliferae*
Periploca linearifolia	*Asclepiadiaceae*
Phyllanthus odontadenius	*Euphorbiaceae*
Pittosporum mannii	*Pittosporaceae*
Plectranthus barbatus	*Labiatae*
Plectranthus edulis	*Labiatae*

Polygonum setulosum	*Polygonaceae*
Polygonum sp.	*Polygonaceae*
Ranunculus multifidus	*Ranunculaceae*
Rhamnus prinoides	*Rhamnaceae*
Rhus natalensis	*Anacardiaceae*
Rhus vulgaris	*Anacardiaceae*
Rubus volkensii	*Rosaceae*
Scutia myrtina	*Rhamnaceae*
Smilax anceps	*Smilacaceae*
Solanecio mannii	*Compositae*
Sphaeranthus napierae	*Compositae*
Stephania abyssinica	*Menispermaceae*
Toddalia asiatica	*Rutaceae*
Trimeria grandiflora	*Flacortiaceae*
Urera hypselodendron	*Urticaceae*
Vangueria madagascariensis	*Rubiaceae*
Vernonia auriculifera	*Compositae*
Zehneria scabra	*Cucurbitceae*
Gerbera viridifolia	*Asteraceae*
Thelypteris confluens	*Thelypteridaceae*

Table 6.3: List of shrubs and herbs species found in Saiwa swamp National Park

Grass and Grass-Like Plants	**Family**
Chloris gayana	*Poaceae*
Cyperus alternifolius	*Cyperaceae*
Cyperus distans	*Cyperaceae*
Cyperus exaltatus	*Cyperaceae*
Cyperus immensus	*Cyperaceae*
Cyperus latifolius	*Cyperaceae*
Cyperus tomaiophyllus	*Cyperaceae*
Echinochloa pyramidalis	*Poaceae*
Hugrophila spiciformis	*Poaceae*
Pennisetum sp	*Poaceae*
Pycreus lankecus	*Poaceae*
Setaria sphacelata	*Poaceae*
Sporobolus africanus	*Poaceae*
Loudentia kagarensis	*Poaceae*
Schoenoplectus corymbosus	*Cyperaceae*

6.5 Discussion

According to Ogutu (1996) and Kavishe (2001) the vegetation of the Saiwa Swamp National Park contains some of the original indigenous vegetation types (such as *Acacia*) of the area most of which have now been cleared for cultivation and settlements. The results show that the species types have not changed much within the park except the noted increase by Gichuki (1998) of elephant grass that has invaded many parts of the swamp. Human activities have major impacts on the vegetation as noted above including the erosion of the banks of the rivers Sinyerere and Kipsaina that feed into the Saiwa wetlands, and the ecological succession of the native *Typha* vegetation by elephant grass (*Pennisetum purpureum*) (Mohamed, 2000). Without any doubt, intensive agricultural activities are a major threat to the Saiwa wetlands and their biodiversity. For example, agro-chemicals used in the many surrounding farms are carried by runoff into the wetlands, thereby changing the chemistry of the waters, triggering vegetation ecological succession (elephant grass has displaced the native *Typha* vegetation) among other ecological changes (Gichuki, 1998; Mohamed, 2000). The decline in the population of sitatunga antelope in Saiwa National Park is attributed to the elephant grass, which impedes the sitatungas' movements and thus making them vulnerable to the predators. Furthermore, the decrease in birds' population and particularly the Crane (*Balearica regulorum*) is attributed to the deterioration of the wetland habitat resulting from inappropriate agricultural practices in the catchment area (Gichuki, 1998).

CHAPTER 7: GENERAL CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

This Chapter attempts a review of the literature on land use and land cover changes, and on issues of water and soil sediments quality in wetlands relevant to the current study and with particular relevance to the Kenyan situation. It attempts to review the current literature status on the research topic with an aim that the findings of this study would add to better scientific knowledge on land use and land cover changes and their impacts on water and soil sediments quality of the wetlands.

7.2 Conclusions

Wetlands play a vital role in providing ecosystem services of water purification and reducing water pollution by filtering heavy metals originating from agricultural activities in the surrounding farms. This makes these waters portable and usable by both humans and livestock downstream. There is, therefore, need to conserve and restore these wetlands.

Results from the present study disclosed a significant land use and land cover change in Saiwa Swamp watershed. Total population also exhibited positive growth mainly as a result of natural increase. By processing and comparing multi-sensor Landsat scenes over five time intervals between 1985 and 2015 in Saiwa Swamp watershed, it was observed that there was an overall trend towards a reduction in shrub/riparian vegetation to agricultural land. Saiwa and neighbouring swamps along river Saiwa are sources of domestic and small-scale irrigation water for horticultural farming. However, increasing human activities are threatening wetland ecology and hydrology through changes in nutrient levels in the waters and soil sediment. The swamp vegetation acts as a natural reservoir that sustains the flow of the river during the dry season and also absorbs dissolved nutrients and filters pollutants that are harmful to users downstream. Other observed land cover transition processes are succession of agricultural land to built-up area and farm woodlots. The main trees planted in these woodlots are Eucalyptus species.

7.2.1 Specific conclusions

The following are the specific conclusions from this study.

1. There was an apparent change in land use and land cover with an overall trend towards a reduction in forest areas and increase in cropland, woodland and built-up areas, linked to increased human population and activities.
2. Soil sediments, nutrients and chemicals from pesticides and fertilizers enter the wetland through water runoff, especially during the wet season, affecting the water and soil quality in the riparian ecosystem.
3. In general, the study found that the swamp plays a vital role of retention of chemicals and metal elements, especially during the dry season when water flow is low, slow and has longer residence time within the swamp to allow for filtration and mopping up of these chemicals and sediments.
4. The floristic list of plants shows that the Park is a rich ecosystem with many diverse plant species.

7.3 Recommendations

From the study, the following recommendations can be drawn:

1. There is need to strengthen the enforcement of laws on physical planning in order to reduce encroachment and destruction of natural resources such as forests and riparian zones.

2. There is need for introduction/enforcement of proven and sustainable farming practices that guarantee soil/water integrity, especially the use of organic fertilizers with minimal tillage.
3. On the basis of the findings of this study, there is need to train farmers, KFS, KWS and county staff on better wetland/natural resources conservation.
4. A detailed ecological survey of the plants be carried out within the Park to ascertain changes since the last detailed surveys in the last 20 years

7.4 Areas of further research

Based on the results of this study, further research needs to be conducted to ascertain the policy implementation and how it affects ecosystem sustainability in the two protected areas. Also more studies should be carried out about other ecosystem drivers and how they impact on ecotourism sustainability. Further monitoring of spatial and temporal land use and land cover changes needs to be undertaken. It is also recommended that a detailed ecological survey of the plants be carried out within the Park to ascertain changes since the last detailed surveys since the last 20 years (Kavishe, 2001).

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