AN ECOLOGICAL AND PALYNOLOGICAL STUDY OF MANGUO WETLAND IN KIAMBU COUNTY, KENYA.

BY

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DECLARATION

I, Esther N. Githumbi, declare that this is my original work and has not been submitted to any other university for the award of a degree.

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ABSTRACT

Wetlands provide vital natural products and environmental services that support human development. The ecological character of wetlands are closely linked with the surrounding terrestrial ecosystems hence land use activities on the catchment area have far-reaching effects on the ecological character of the wetland.

The overall goal of this study was to investigate the past and contemporary dynamics of vegetation communities in response to environmental changes at Manguo wetland, Kiambu County Kenya. This was achieved through determining present vegetation structure and distribution, assessing water and soil characteristics and reconstructing the historical vegetation changes through palynology.

The study area measured 7.5 ha, sampling for vegetation and soils was carried out at regular intervals along 14 intersecting transects. Vegetation sampling was carried out both during the dry period and the wet period so as to capture changes between seasons (October/November and January/February). Top and sub soil samples were collected from selected quadrats in the flooded grassland and dry ground zones while water samples were obtained using a standard sampling procedure from the existing open water body. The soil and water samples were transported for physical and chemical analysis at the Kenya Agricultural Research Institute (KARI). A Russian soil corer was used to extract a 2.25m deep soil core in sections of 0.5m. The core sections were lithologically described then wrapped in PVC and aluminium foil for transportation to the Palynology Laboratory at the National Museums of Kenya. The core was sub sampled at 0.1m intervals for processing and analysis of pollen content.

The modern vegetation sampled was from 20 species from 8 orders and 12 families identified in both the wet and dry period samples. The vegetation abundance was higher during the wet period sampling (6387 individuals) compared to the dry period sampling (4272 individuals) with *Pennisetum clandestinum* having the highest abundance in both periods. The wet period diversity was also higher at $H^I = 1.05$ while the dry period diversity was $H^I = 0.64$. The species richness calculated using the Margalef index was higher during the dry period at 4.13 than the wet period at 3.94. The plant species composition changed along soil moisture and nutrient gradients but not significantly. However seasonality and zonation also did not have a significant impact on the composition and distribution of the wetland vegetation.

The soils though water logged had adequate levels of nutrients as per the Kenya Agricultural Research Institute (KARI) standards. The Ph levels were found to have significantly dropped from the 2007 level of 7.03 to 5.12. The water was also determined to be of irrigation quality but not direct consumption due to solid waste pollution. The canonical correspondence analysis (CCA) showed that the soil characteristics with the highest influence on vegetation distribution were variations in pH, copper and potassium content.

The sediment core revealed the water sheds historical succession from high forest species abundance to open grassland in the recent past. There was high presence of *Juniperus, Olea* and *Podocarpus* which increased up the core. *Acacia, Apodytes, Cordia* and *Croton* present at the lower levels gradually but consistently reduced up the core and completely disappeared by the 60cm level. The presence of Amaranthaceae/Chenopodiaceae and Asteraceae is consistent and increased up the core, they are indicators of human impact mainly cultivation and degradation respectively. Poaceae and Cyperaceae are present throughout the core at different abundance levels and are driven by moisture levels changes (climate).

These vegetation changes observed across the wetland temporally and spatially are evidence of both climatic and human induced pressures on upland wetlands in Kenya. The information can be used in the development of conservation measures for Manguo wetland but this can be replicated and tailored to specific ecosystems in the development of conservation policies and also in ecological models.

CHAPTER ONE

INTRODUCTION

1.1 Background

Wetlands are transitional zones (ecotones) between terrestrial and aquatic systems where the water table is usually at or near the surface, shallow water covers the land and at least one of the following attributes holds: The land predominantly supports aquatic plants at least periodically, undrained hydric soils are the predominant substrate and at some time during the growing season the substrate is saturated with water or covered by shallow water as described by Cowardin *et al.* (1979). Swamps, marshes and bogs are some of the common names used to describe wetlands. Wetland ecosystems are dominated by the influence of water; they possess characteristics of both terrestrial and aquatic ecosystems and properties that are dependent. Wetlands support a wide array of flora and fauna and deliver many ecological, climatic and societal functions.

Wetlands are dynamic environments that experience natural fluctuations in both water level and water quality. As a consequence some wetland plants have adapted and are able to tolerate both flooding and short periods of drought within a single year. Aquatic vegetation reflects the nutrient status of their immediate surrounding by their presence/absence and abundance (Uotila, 1971). The occurrence and composition of plant communities is determined by a complex interaction of several factors including climate, soil type, position in the landscape and competition between plant species. The natural quality of terrestrial water bodies is determined by quality of surface run off and ground water discharge (Fisher, 1992).

Upland wetlands tend to occur in depressions in the landscape, the persistence of the wetlands throughout the year depends on the depth of the depression in which they occur, the depth of water in the wetland, the catchment area supplying the wetland with water, rainfall patterns, and past and current disturbances. Upland wetlands can be classified according to the period of time the wetland is flooded. They occur as near permanent (rarely dry), intermittent (often seasonally dry) or ephemeral (only occasionally full).

The vegetation of the upland wetlands ranges from dense sedge land to grassland. Around deep lagoons or lakes the vegetation occurs on the shores and in the shallower reaches, while shallow or dry-wetlands may have sedges and grasses extending all the way across.

The main characteristics of the upland wetlands are: they occur in deep depressions in the landscape, occur on basalt-derived soils or soils derived from other rock types such as granite, support a range of vegetation such as water plants, sedges, forbs and grasses; and there are no shrub or tree species that occur naturally within these wetlands, though shrubs and trees in areas surrounding the wetlands can play an important role in controlling run-off and buffering impacts.

There has been sustained international effort for the last four decades to save wetlands mainly through the “Convention on Wetlands of International Importance Especially as Waterfowl Habitats” which is commonly known as Ramsar Convention after the name of the town in Iran where it was first held in 1971. According to the Convention, wetlands are defined as," areas of marshes, fens, peat lands of water, whether natural or artificial, permanent or temporary with water, that is static or flowing, fresh, brackish or salt including the areas of marine water, the depth of which at low tide does not exceed six meters". The economic, social, cultural, biodiversity and ecological significance of wetlands are widely acknowledged, and global efforts are being sought to prevent further degradation and loss (Ramsar Convention Bureau, 2000).

Many of our watersheds and their related wetland ecosystems are currently damaged, water-starved and often marginally functional (Erwin, 2009). In Kenya over the last fifty years wetlands have experienced major losses due to climate change, land use changes, upper catchment impoundments, and agricultural irrigation schemes and species introductions. The effects of these changes have led to the loss of livelihoods for communities dependent directly on wetland resources. Rapid biodiversity loss in these wetlands has created a need for better assessments of the ecosystem functions, socio-economic values and the important biodiversity.

Wetlands are ideal repositories of historical information as the waterlogged conditions in wetlands foster the accumulation of peat by excluding atmospheric oxygen from the soil and retarding the decomposition of dead vegetation. This anoxic environment favours the preservation of the plant fossils used in environmental reconstruction.

Land cover changes brought about by human activities also have major influence on the impacts of climate variability, especially extreme events. Land cover modulates the expression of floods, their geo-morphological impact and their impacts on humans. Changing the land uses surrounding these wetland complexes can alter the water chemistry, structure, and functions within the fen or other wetland areas, which in turn affect the central bog ecosystem (Bledzki *et. al*, 2007).

1.2 Description of Manguo wetland

Manguo is a privately owned wetland covering an area of about 8.1 ha. The origin and history of the wetland is poorly understood however the name Manguo in the local ethnic kikuyu language means “the place of the hippopotamus”. Information available from the octogenarian indicates that hippos were last seen in the swamp around 1938 (Waithaka, 2004). Their disappearance is hypothesized to have been as a result of human activities.

The wetland was subdivided in the 1960’s by the county council where some parcel was given to individuals and the rest remained under their jurisdiction. Thus it is privately owned even though natural resources such as wetlands are public property. This has caused ownership disputes and neither party (government nor local people) has been able to effectively utilize the land.

In the 1990’s there was the formation of MECONG (Manguo Eco-Tourism, Enterprise and Conservation Group) to consolidate use of the wetland and ensure sustainable use, and later Manguo Land Owners Association was also formed to bring together the Manguo land owners (MLAO) for joint conservation efforts.

In 2007 there were plans of changing the wetland use to an ecotourism site for bird watchers due to the high diversity of birds (resident and migrant species) by the Limuru county council. However the plans were shelved after there was destruction of the infrastructure developed i.e. a fence and walkway put in place for that venture.

Manguo wetlands’ existence has been threatened mainly by the pressure caused by the human activities and long term variations in meteorological conditions which have affected its morphology and hydrobiology. Whereas natural phenomena cannot be easily controlled, it is important that man's role in affecting the extent and functions of this wetland be checked if we are to preserve it. It is important to identify and quantify the resources of the wetland such as the floral and faunal biodiversity together with the soil and water quality for effective conservation and management planning.

1.3 Land use around Manguo wetland

Before the 18th century most of Kenya was a thick forest Limuru region included, there were no signs of cultivation (Muriuki, 1974). However in the 2nd half of the 18th century and the 1st half of the 19th century there was rapid expansion by the Kikuyu community. They were cultivators and land tenure was on the basis of first come first served with clearance of virgin land. Since then there has been continuous forest clearance and the whole area is now open and used for human settlements.

Small scale agriculture is the main land use type around Manguo, the area has a high number of settlements and before 2007 the wetland was used as a dumpsite where residents would dump their garbage at the wetland next to the water and burn it, there was a slaughter house that also dumped its waste right into the wetland. This however stopped when an initiative by the MECONG, MLAO, the Limuru County Council, the University of Nairobi and the National Museums of Kenya to promote wise use of the wetland was established. The wetland was fenced and dumping was strictly prohibited.

Reconnaissance visits that I undertook between in August and November 2011 revealed that the garbage dumping and car washing activities which were previously rampant no longer take place due to the fence that had been erected thus protecting it. Though the fence was uprooted, the people responsible for the direct dumping of garbage and the car washes had not returned.

1.4 Past conservation initiatives of Manguo wetland

In 2007 a baseline study carried out by the University of Nairobi (UoN) and National Museums of Kenya (NMK) funded by the Royal Netherlands Embassy Small Grant Programme (KNIP) brought the MECONG group members together for the idea of developing the wetland into an ecotourism and conservation site. It was observed that wetland resources were gradually getting depleted and this was attributed to the activities of individual members of the local community such as overgrazing, fodder collection, waste dumping, car washing, oil spills and bird egg collection (Macharia and Thenya, 2007).

Deterioration of the wetland was possibly due to lack of a management plan and although it is clear that the wetland is under private ownership, from the community perspective it is not clear who is responsible for the management, creating a lot of confusion and thus many conservation stakeholders and potential donors shy away from the wetland due to the property ownership wrangles.

There were several conservation activities that had been planned by the Manguo Eco-Tourism, Enterprise and Conservation Group (MECONG) that included developing a bird watching platform, fencing to control utilization, charging a grazing fee of K.shs5 per animal per day, planting of indigenous tree species along the perimeter fence and developing a management plan to guide activities for sustainable use. However observations carried out in August 2011 show that the fence and the bird watching platform were destroyed and the municipal council was not aware of the culprits, also the grazing fee was not implemented as there were no measures put in place to enforce it.

Community and grass-root participation in wetland restoration activities often contribute to their long-term success by educating local communities and focusing attention on the causes of degradation and that is why for example even if the fence was uprooted the people responsible for dumping have not returned. Community participation is also important for creating employment and ensuring a more equitable distribution of benefits. However, care must be taken to properly train community volunteers and provide appropriate guidance from experienced managers and restoration professionals; this would also prevent destruction of property as observed because the benefits are perceived to be for the whole community. The MECONG and MLAO strive to achieve this.

A vegetation study made it possible to identify and quantify the floral diversity. Soil and water samples were obtained and analysed to determine their physical and chemical properties. To determine the vegetation changes over time pollen analysis (palynology) was done. This was important in giving Manguo a current conservation status and describing the floral diversity which is a function of biological, physical and chemical environment.

1.5 Justification and significance of the research

Wetlands are considered to be amongst the most valuable ecosystems and yet there has been a consistent and increasing threat towards them. Even in protected areas wetlands appear to be affected by human induced pressures mainly infrastructure development for tourism such as roads, airstrips, camp sites and hotels which lead to abstraction of water mostly meant for wildlife and waste generated from residential lodges tend to be dumped in the nearest wetlands which also happen to be water sources for wildlife within the protected areas.

Outside protected areas e.g. wetlands in local areas, the threats increase due to lack of utilization regulations. The threats include; drainage and cultivation, deposition of liquid and solid waste, harvesting of materials, water abstraction, grazing, burning, excavation of soil/sand and rocks amongst others all of which are observed in Manguo wetland.

The low level of awareness on importance of wetlands and lack of baseline information about the physical, chemical and biological characteristics has been the main cause of wetland loss as they were perceived to be wasteland. Therefore there is a need to acquire this information and to use it to conserve our wetlands. This is especially important in ecosystems where there has been little or no ecological monitoring and environmental degradation is occurring. For example, small wetlands where data is not available as very little research has been carried out in them, therefore there is a great deal of unknown information that is continually been lost with the constant degradation of these ecosystems and Manguo wetland is a good example of a small wetland of extreme importance.

It is necessary to study the effects of these threats on the ecological integrity of wetlands. Drainage of some parts of the wetland has led to a decrease in the water level and change in vegetation composition and distribution. Manguo is an isolated wetland that has no management plan; this implies that there may be a high rate of biodiversity loss due to spatial isolation and overutilization of resources.

Vegetation inventory, monitoring and analysis is an important method of understanding and quantifying human impacts on the environment by evaluating the vegetation changes observed so that the effects of land use can be managed in a sustainable manner. Thus it was important to determine the vegetation status of the wetland.

Palaeoecological records for the area are not available and this study provides that information albeit at a very basic level of which future studies can build upon. The information provided can act as the backdrop against which land use and resource management debates are argued by availability of information on pre-anthropogenic plant community structure. This would be useful in determining whether the objectives of the Manguo Eco-Tourism, Enterprise and Conservation Group have been achieved. The information obtained can also be used for rehabilitation of the wetland because by determining the species that were originally present in the wetland and the present physical characteristics then selection of species to be replanted would be based on this information.

This study sought to identify the vegetation community structure of Manguo wetland, determine the soil and water qualities and determine the vegetation change that had occurred at the wetland and its environs over time and the impacts of intensifying human activities on the structure and composition of the wetland.

1.6 Research questions

The research questions that guided the study were:

1. What is the existing plant community structure in Manguo wetland?
2. What are the soil and water characteristics?
3. What soil and water characteristics affect the vegetation distribution?
4. How has the vegetation changed over time?

1.7 Research hypotheses

Utilization of wetlands affects the structure and function of the ecosystem. The impacts cause changes in the ecological succession that can be detected by the temporal and spatial changes in vegetation composition, abundance and distribution. At Manguo wetland there has been an the extraction of water for human consumption, dumping and burning of solid waste in the wetland leading to large patches of burnt areas and the high level of grazing livestock. This has led to reduction in water volume, presence of solid waste and increased nitrogen content in the wetland soil and water amongst others.

The research hypotheses for this study were therefore:

H_o: Plant community structure and distribution do not change with soil and water characteristics.

H_o: Natural vegetation has not significantly changed overtime.

1.8 Objectives

The main objective of this study was to determine Manguo wetland vegetation composition and structure overtime analyse if the current vegetation responds to local soil and water conditions and identify land use around Manguo wetland and the impacts. This was achieved through the following specific objectives:

1. Determining the existing plant community structure in Manguo wetland.
2. Assessing the soil and water characteristics and their influence on vegetation distribution.
3. Reconstructing vegetation change overtime through palynology.

1.9 Limitations of the study

A few problems were encountered during the study and the main ones included:

1. Limited background information about Manguo wetland as it has not been widely studied.
2. Limited resources especially funding thus some tests such as carbon dating of the soil core samples could not be carried out.
3. Access to the study area was limited especially because of insecurity. Sampling could only be carried out between 9 am and 4 pm; markers could also not be left because of interference.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Understanding of the environment is a very important aspect for proper planning, utilization and management of natural resources and that is why habitat studies have become a focal point in ecology (James *et.al*, 1990).

The ecosystem approach, which is defined as a strategy for the integrated management of land, water, and biological resources that promotes conservation and sustainable use in an equitable way (Finlayson *et al.* 2011) is usually the best approach for ecological studies. The physical, chemical and biological components of the environment and their functioning at different levels are studied in order to understand ecosystem processes.

Historically, the development of civilizations has led to a shift in the pattern of water use from rural/agricultural to urban/industrial. This in turn impacts on the wetland utilization therefore wetland health. Water quality impacts wetland plant and animal communities and changes in water quality invisible to the naked eye can result in irreversible impacts. Water quality parameters influence wetland health, thus water quality has to be determined and monitored.

Paleoecology which is the study of ecosystem history over various time scales using sedimentary records provides a unique temporal perspective on patterns, causes, and rates of ecological change due to natural, hydrologic, climatic variability and anthropogenic activity. Paleoecological records providing baseline data on the pre-disturbance response of ecosystems to climate variability should be integrated into ecosystem modeling efforts to maximize the likelihood of sustainable ecosystem restoration.

Historical evidence is essential for understanding the nature of human-environment interactions for future use. To understand the complex and rapidly changing human-environment interaction, historical information and information on land use is vital. Past distributions of pollen and plankton from sediment cores can be used to derive quantitative estimates of past climate (e.g., temperatures, salinity and precipitation) via statistical methods calibrated against their modern distribution and associated climate parameters (Jansen *et al.* 2007).

2.2 Kenya's major drainage basins and wetlands

Wetlands cover less than 9% of the earth's land surface, but provide habitat to disproportionately high numbers of species such as water birds, amphibians, fish, invertebrates and a variety of flora (Mitsch and Gosselink, 2000).

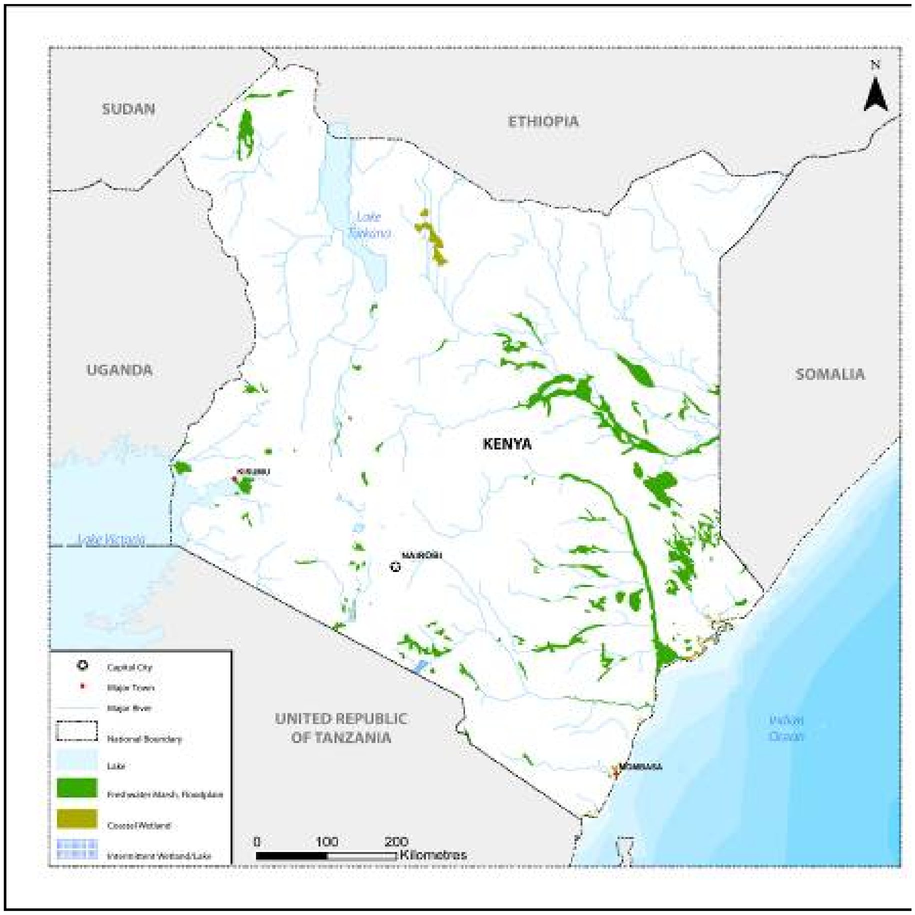
According to the RAMSAR convention wetlands are categorized into three, the marine/ coastal wetlands, the inland wetlands and the human made wetlands. They take many forms and examples include: marshes, estuaries, mudflats, mires, ponds, fens, swamps, deltas, coral reefs, lagoons, shallow seas, bogs, lakes, and floodplains, irrigated lands, waste treatment ponds. Wetlands are categorized depending on their biological and physical characteristics such as nutrient content, salinity levels.

Seasonally moist or flooded lowland areas cover an estimated 228 million ha in sub-Saharan Africa in contrast to the large wetland areas of the Lake Victoria and Okavango Basin and the Nile catchment's area (Becker, 2006). Fresh water wetlands occur locally in arid to semi-arid regions of East Africa (Ashley *et. al*, 2004).

In Kenya, wetlands cover approximately 14,000 km^2 (3-4%) of the surface area of the country (MENR 2012). In 1995 Kenya was classified in the category of water stressed countries and in 2025 it's predicted to be among the 8.3% countries classified as water scarce (Gardner-Outlaw and Engelman, 1997, UNEP, 2012).

Swamps are the second most productive of the four most common wetland types (MWW, 2012). They are rich in living and non-living natural resources, and are important sources of food, water, medicinal plants, fuel wood, materials for building and handcrafts.

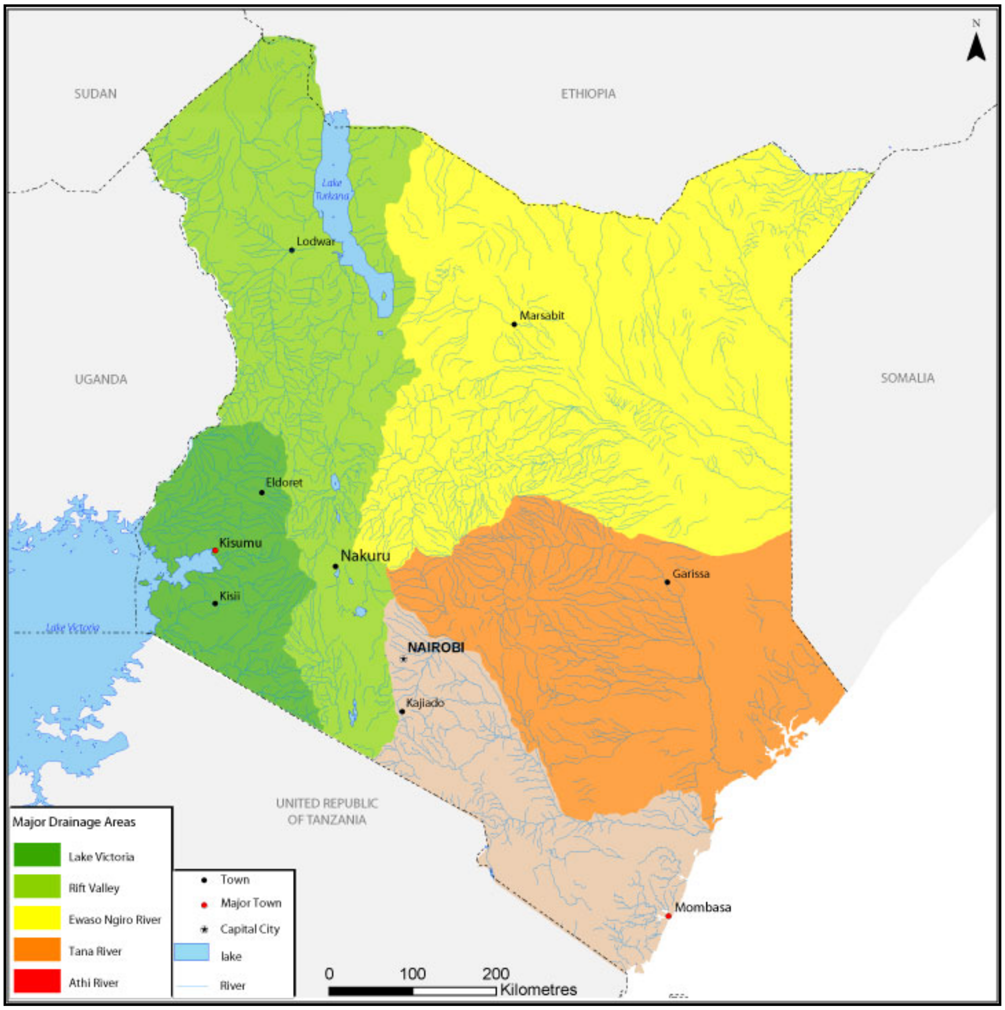
As shown in figure 2.1 Kenya's four largest inland water bodies (Lake Victoria, Lake Turkana, Lake Naivasha, and Lake Baringo) account for about 1.9 per cent of the land area. The majority of Kenya's lakes, including both saline and freshwater, and closed and open basin systems, are located within the Great East African Rift Valley. Kenya's major permanent rivers originate in the highlands. The Nzoia, Yala, Sondu Miriu, and Migori rivers drain into Lake Victoria. The Ewaso Ngiro River is found in the northeastern part of the country and the Tana and Athi rivers flow in the southeastern part. The rivers draining into Lake Victoria (covering over 8 per cent of Kenya's land area) provide about 65 per cent of Kenya's internal renewable surface water supply. The Athi River drainage area (11 per cent of Kenya’s land area) provides 7 per cent, the lowest share among Kenya’s major drainage areas (Survey of Kenya, 2003 and Ministry of Water, n.d.).



SOURCE: World Wildlife Fund, 2005.

Figure 2.1: Kenya's Largest Wetlands.

Kenya has a high number of wetlands and amongst the largest include the shallow lakes Nakuru, Naivasha, Magadi, Kanyaboli, Jipe, Chala, Elmentaita, Baringo, Ol'Bolossat, Abseil and Kamnarok; the edges of Lake Victoria and Lorian, Saiwa, Yala, Shompole swamps; Lotigipi swamp (Lotagipi) and Kano plains; Kisii valley bottoms and Tana Delta; and coastal wetlands.



SOURCE: Water Research Institute .2007

Figure 2.2: Kenya major drainage areas.

Kenya's major drainage areas are categorised into five: the Lake Victoria, The Rift Valley, The Ewaso Ngiro River, the Tana River and the Athi River.

2.2.1 Importance of wetlands

The centrality of water in our lives – social, economic, political and spiritual cannot be overestimated (Töpfer, 2003). Wetlands are important for the ecology of the surrounding landscape, human livelihood, conservation of biodiversity and the recharge of groundwater. The wetlands are also critical for agricultural activities due to their very fertile soils formed by the accumulation of silt and slow decomposition of organic matter (Moore, 2006). These are services that are freely offered by nature and would be difficult and expensive to mimic.

The influential Millennium Ecosystem Assessment recognizes the enormous global economic importance of wetlands, valued at up to US$15 trillion dollars in 1997 (Millennium Ecosystem Assessment MA, 2005). They are among the most utilized natural resource bases in the environment and have been most effectively treated as common property resources from time immemorial. Over centuries, the wetlands have been providing wider opportunities for the millions of rural people to make their livelihood through harvesting diverse resources of both plant and animal origin.

Long regarded as wastelands, wetlands are now recognized as important features in the landscape that provide numerous beneficial services for people and for fish and wildlife. Wetlands are multi-functional and are used by diverse stakeholders that interfere to various degrees with the natural ecosystem.

In Africa during pre-British regime, the wetlands were exclusively used as common property resources for fisheries, cattle grazing and other various purposes round the year. The access regulation to leased wetlands was to enforce strictly fisheries purposes. Harvesting of other resources from wetlands was almost unregulated. Mostly the poor women and children collected plant based resources such as food items, vegetables and livestock fodder almost freely. Access to the resources by the poor people was unregulated and substantial numbers of rural households living around the floodplains still carry out subsistence fishing in the wetlands.

Prolonged periods of water availability and relatively fertile soils provide wetlands with a large potential for the expansion and intensification of agricultural production, particularly as they are often considered to be less vulnerable to human intervention than the uplands (Dixon, 2002).

The spring-fed valley heads of the inland valley wetlands and small mountain swamps of Eastern Africa so far have received little research attention. However, these small wetlands cover some 12 million ha in Tanzania and Kenya alone. They fulfill numerous social and agricultural functions, are islands of biodiversity, provide clean water and are possibly important sinks for carbon. Their recent use as agricultural production sites results in user conflicts for land and water and the loss of their ability to fulfill the diverse functions. There is a need to reconcile demands for increasing production with concerns for environmental protection.

2.2.2 Functions of wetlands

Wetlands are multi-functional and are used by diverse stake holders to different degrees. Wetlands fulfill natural, social and agricultural functions and there functions can be classified as natural, agricultural and social (Richter *et al.*, 1995). The range of services offered depends on the type, size and location of the wetland. They perform functions at local, regional and global scales and even though they are not measurable they are critical for the world.

The natural functions involve the wetlands roles as physical space and that they provide plants and animals' habitat and their role as buffers against droughts and floods, filters and providers of clean air and fresh water, shoreline stabilization and storm protection, climate change mitigation and adaptation.

Wetlands are very important water reserves, recharging aquifers, and thus constitute valuable sources of fresh water. They have been shown to play a potentially important role as sinks for carbon (Matthews and Wassmann, 2002). Of a total of 300 peta grams of C stored globally in wetland soils, some 15% are found in sub-Saharan Africa. However, in connection with inappropriate agricultural use they can also become important sources of climate-relevant trace gases such as methane and nitrous oxides.

The agricultural functions of wetlands involve the provision of a large and high-quality resource base for production (soil, water, and nutrients), source of raw materials, and of regulatory functions on water flow, soil fertility, and biodiversity (e.g. natural enemies of crop pests). All these combined allow for intensive and potentially highly productive agricultural activities such as crop production, livestock rearing, and agro-forestry. Wetlands are also an important source of food, the fresh water ecosystems whether natural or manmade (aquaculture) are a major source of proteins. According to Wood *et al* (2005) approximately 10% of wild harvested fish are caught from inland waters.

The social functions of wetlands relate to their role as sites for human settlements, for industry and for recreation. As major reservoirs of floral and faunal genetic diversity, wetland ecosystems support a range of non-agricultural activities, including the harvesting of thatching material and timber, hunting, fishing, recreation, and tourism. Many of these activities are of particular importance to poorer households, and fragile social groups. In areas of increasing urbanization, wetlands are systematically destroyed by drainage to serve as sites of industrial expansion and housing development.

This diversity in functions and uses results in a variety of stakeholders. These may include farmers, foresters, governments and private organizations and also the rural and urban population at large who use the land for settlement, the water for drinking, washing and technical uses, and the raw materials for a whole range of household and industrial purposes (Gopal et al., 2000).

The value of a wetland is different from the wetland function. The value is an estimate of the importance or worth of one or more of its functions to society and can be determined for example by the revenue generated from the sale of fish that depend on the wetland or by the tourist income associated with the wetland, or by public support for protecting fish and wildlife. The large-scale benefits of functions can be valued, however determining the value of individual wetlands is difficult because they differ widely and do not all perform the same functions or perform functions equally well.

Implementation and adoption of the Ramsar Convention guidelines has been successful for wetlands of international, regional and national importance, however small local wetlands are ignored and thus utilization and management is left to local communities which often have little or no interest in their conservation. Generally wetlands are perceived as less important due to their small size.

Small sized and seasonal wetlands are mostly found on private or community owned land, which make conservation interventions by government agencies difficult to implement with a good example being the Manguo wetland. Though small-sized wetlands are sometimes seasonal, they can cover large areas during rainy seasons as well as be very productive and rich in biodiversity (Chambers, 1999).

2.3 Vegetation of upland wetlands

Macrophytes are plants that grow in or near water and tend to dominate the wetlands. They are an important component of wetlands and the main wetland vegetation type. They are aquatic plants with different growth forms that are common in particular types of water bodies i.e. they are emergent macrophytes, submergent macrophytes and floating-leaved macrophytes (Wetzel, 1983). Their ecological significance include habitat for organisms, breeding sites, acts as substrate for aquatic invertebrates, oxygen production and serve as food for some fish and other wildlife. The composition of aquatic flora influences the littoral invertebrates (Nurminen, 2003).

Macrophytes can be indicative of either the maintenance of high water quality standards or deterioration through pollution and wetland alteration. Macrophytes are involved in feedback mechanisms which keep the water clear even with high nutrient loading (Moss, 1990).

Seasonal wetlands tend to have a higher diversity of aquatic and fringing vegetation in comparison to permanent wetlands. This is because there are a greater number of microhabitats in seasonal wetlands which increases macro invertebrate species richness and provides food and shelter for water bird populations. Seasonally waterlogged areas such as swamps have been found to support very high levels of plant species richness.

2.4 Impacts of wetland soils and hydrology on vegetation distribution

Wetland ecosystems provide fundamental ecological functions including the regulation of water regimes as well as providing habitats for flora and fauna. In a wetland the soil and water characteristics do not fluctuate extensively over time unless there are external inputs.

The degree of wetness controls wetland soil properties, which in turn controls the biotic community or habitat. The balance between aerobic and anaerobic conditions is critical to wetland function (DeKeyser, 2006). Water logging tends to exclude oxygen from the soil and plants have evolved many ways to deal with this, leading to the evolution of hundreds of specialist wetland and waterside species. Only hydrophytes, plants that are adapted to an environment where water is present in the root zone either permanently or for extended periods of time, can survive in such soils. The type of soil, the amount of organic matter, the depth to which the water table rises, the climate, and the season and duration of high water will determine the kinds of plants that will grow in a wetland. Therefore, wetland types are identified, in part, by the kinds of plants that grow in them and the degree of surface flooding or the degree of soil saturation due to a high water table (Welsch *et al.,* 1995).

2.5 Drivers of change in wetland ecosystems.

Human activities have been identified as the major drivers of global environmental change on the planet and as a consequence directly influence biodiversity (Vitousek, 1994). Urbanization dramatically alters the natural hydrologic cycle. As urban structures such as roads and buildings are built, the amount of impervious area within a watershed increases. Increase in impervious area increases the volume and rate of runoff, while decreasing groundwater recharge.

Urbanization also increases the type and amount of pollutants in surface runoff. Infrastructure development, land conversion, intensive land use and the massive deposition of pollutants in water threaten all ecosystem functions that produce our freshwater resources (Verhoeven *et al.,* 2006). Because of the slow development of ecosystems most of these quick and dramatic changes are irreversible (Anker, 2002).

Most low latitude regions and East Africa in particular have been experiencing a long-term trend to increasing aridification over the last several million years (Cane & Molnar, 2001) which means there has been a consistent loss of wetlands.

Wetland loss has been on the rise in developing countries as a result of wetland conversion to agricultural land, fishponds, and urban settlements. Recent studies in East Africa have also indicated expansion of small-scale farming and horticulture in wetlands as important drivers of wetland loss (Reid *et al.,* 2005.).

When wetlands are degraded, the broad range of benefits they produce begins to deteriorate and eventually vanish. In some cases, degradation occurs because one particular benefit is valued above all others, such as water supply for irrigation in agricultural production systems or domestic use while ignoring their function as a habitat.

2.6 Palynological study of wetlands

Past studies suggests that East African low and high altitude ecosystems have been subject to extensive forest loss and fragmentation as a consequence of human activity in the recent past. Multi-proxy palaoecological evidence is applied to explore the nature and timing of long-term human impacts (Lin *et. al.,* 2007, Mathai, 2011).

Archeological evidence should be able to show the vegetation transition most often from a thick forest to introduction of cultivated plants. Accumulated sediments contain plant macro and microfossils; lakes, swamp and bog sediments trap evidence from the surrounding environments for paleoenvironmental reconstruction (Muiruri, 2008). The plant microfossils provide evidence of historical changes in the surrounding environment.

These sediments are the indicators studied in palynology which is concerned with the structure and formation of the pollen grains and spores and their dispersion and preservation, other proxy apart from the pollen grains and the spores include charcoal, phytoliths, and diatoms amongst others.

The impacts of human activities on the environment particularly on vegetation are best recorded in lake sediments in form of pollen sequences, charcoal stratigraphy, opaline silica bodies and charred leaf cuticles. They are therefore important in paleoenvironmental construction and also as indicators of human impact and changes in land use overtime.

2.7 Degradation of wetlands.

The loss of natural habitats through destructive anthropogenic activities has been identified as one of the major drivers of environmental degradation. This loss is more prevalent in developing countries where poverty and ignorance of the value of biodiversity is rampant.

Wetland degradation is defined as the alteration of an existing or intact wetland resulting in a simplification or disruption in its structure, function and composition and, in turn, a loss of biodiversity and ecosystem services. This is most often caused by human activities or disturbances that are too frequent or severe to allow for natural recovery (Alexander and McInnes, 2012).

The degradation and loss of wetlands is more rapid than that of other ecosystems. Similarly, the status of both freshwater and coastal wetland species is deteriorating faster than those of other ecosystems as reported by (MA, 2005).

The Millennium Ecosystem Assessment in 2005 reported that wetland ecosystems are increasingly been threatened by human activities such as increased pollutant loads, unsustainable extraction of water and other resources, encroaching on the wetlands for farmland and building of homes. Over application of nitrogen fertilizer and animal manure in an attempt to produce unrealistic yields or to offset anticipated losses increases the potential for groundwater contamination and should be avoided.

Increasing water pollution, unchecked water withdrawal, wastage and degraded water catchment areas are endangering water availability, in turn aggravating health risks for the population (GTZ, 2008**).**

One consequence of widespread wetland losses is the decline of wetland-dependent species such as amphibians, invertebrates, and waterfowl, as well as species that are primarily terrestrial but use wetlands as refugia and for subsidy (Hansson *et al*., 2005).

It is further asserted that the water crisis is also due to the wave of droughts, poor management of the water supply, under-investment, unfair allocation of water, and a huge population explosion of thirty-fold increase since 1900 (Water Partners International, 2008).

Peri-urban areas form belts of non-urban land fringing metropolitan centers while rural areas are settled places outside cities (Rechner, 2008). Peri-urban areas are often neither fully urban nor rural but form a mosaic of often incompatible and unplanned uses including agriculture.

Manguo wetland is located in a peri-urban area. Due to unplanned heavy settlements, water and sanitation services are often inadequate/lacking in entirety. They are the areas where the most unchecked utilization of wetlands would take place due to the lack of infrastructure needed to supply water to homes.

2.8 Summary of research gaps

Several research gaps were identified at Manguo wetland as important aspects that need further studies to acquire the necessary information for management and conservation and they include:

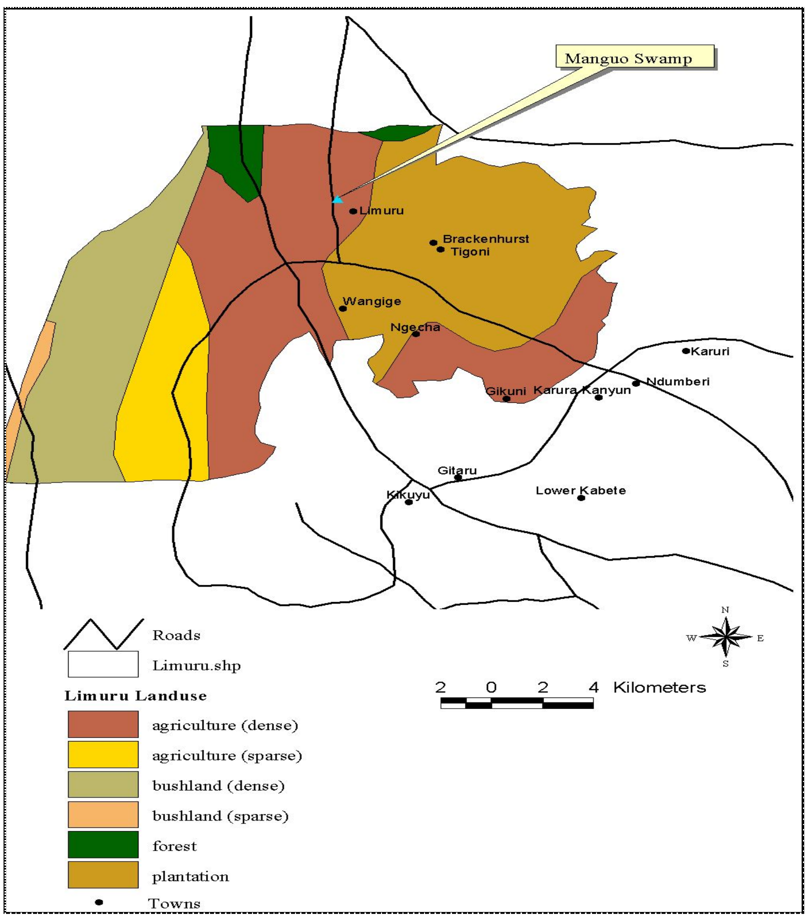
- Information on Manguo wetland plant community dynamics which is unavailable.
- Effects of soils, water and hydrology on the wetland vegetation.
- Response of wetland vegetation to human disturbance to monitor impacts of the human activities on Manguo wetland and the watershed in general.
- Historical vegetation development in a wetland so as to understand if and what have been the changes in vegetation structure overtime and dating of the samples to give a time scale for the changes in vegetation.
- Mophometric characteristics of Manguo wetland essential for determining the sources of the water in the wetland.

CHAPTER THREE

STUDY AREA, MATERIALS AND METHODS

3.1 Study area

Manguo wetland is located in Limuru division of Kiambu County. The county had a population of 1,623,282 in 2009 as per the Kenya National Bureau of Statistics (KNBS, 2009). The region is highly productive and the main land use is agriculture, both intensive and subsistence (Figure 3.1).



National Museums of Kenya-GIS LAB

Figure 3.1: Main land use around Manguo wetland

Limuru is one of the five divisions in Kikuyu district with an area of 286km^2. Manguo wetland is located in an area of dense agricultural use surrounded by natural forests and plantations and is next to the Nairobi-Nakuru highway.

3.1.1 Location

Manguo wetland is a small upland wetland situated in Limuru division, Kiambu County, Kenya. The wetland is located at latitude 01^0 06’ 19.6’’ S and longitude $36^0$37’ 58.44’’E at an elevation of 2200 meters above sea level (Figure 3.2). Manguo wetland occupies an area of 8.1ha and primarily depends on rainfall, surface runoff and underground seepage for its water supply.

3.1.2 Climate

Limuru area experiences bimodal rainfall with an average annual rainfall of 1200mm in two wet seasons with the highest amount falling between April and May with the second wet season occurring in October to December. The annual mean temperature ranges are between 15.2^0C and 17.6^0C during the cold season and 20^0C to 24^0C during the hot season. Altitude is the major factor influencing the climate in the area. Limuru area frequently experiences dense mist and frost and that could be another possible source of moisture.

Water supply to the wetland is from underground seepage, rainfall, surface runoff and mist. The swamp therefore experiences changes between the seasons in the swamp area and volume that are not only locally determined. Due to underground seepage the water level is still quite high during the dry season, the source of the water being the highlands.

3.1.3 Geology

Geology of Limuru division is characterized by both tertiary and quaternary volcanic material. Tertiary volcanic material of middle and upper age are mainly composed of alkaline type and include basalt, phonolites, trachytes and rhyolites with quaternary volcanic of Pleistocene being composed of alkaline material also. The area is also characterized by existence of some chromite mineral deposits especially in the northern part of the division (Waithaka, 1996). This is in the lower highland zone (LH1-LH2) and the soils found in this region are well drained, extremely deep, dusky red to darkish brown, friable clay with pisoferric or petroferric material (eutric nitrosols). The main farming system is tea-dairy, though maize, pyrethrum, horticultural crops, fruits, and sheep farming are also found.

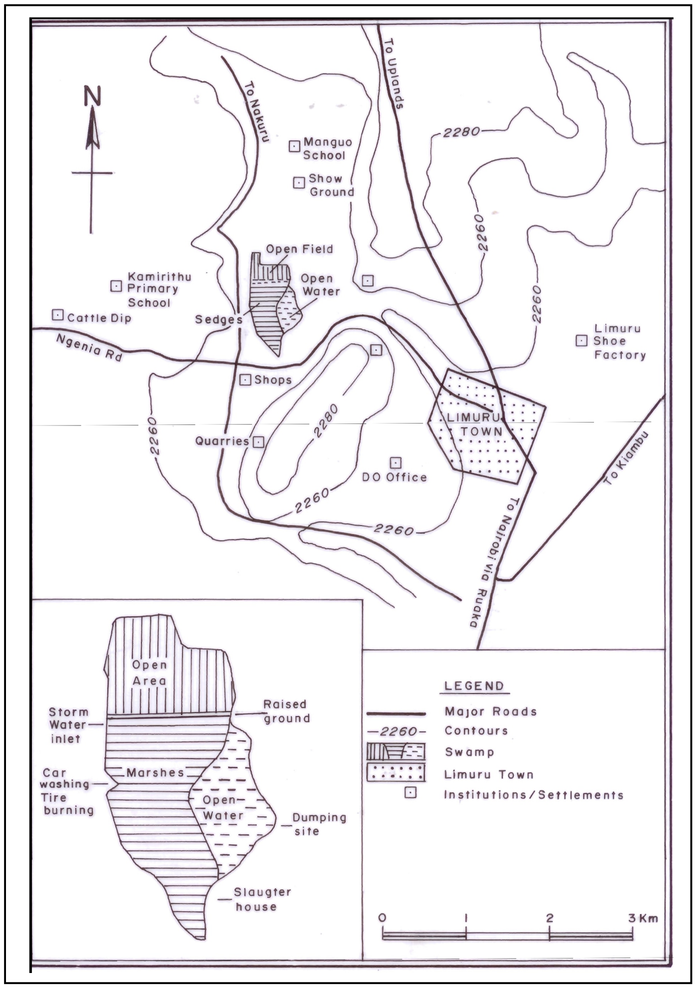


Figure 3.2: Location of Manguo wetland.

The map shows the position of Manguo wetland within the locality, its shape, elevation and the physical zonation based on water level. The map also shows some human activities that take place within the wetland.

3.1.4 Local landscape

The wetland is located in the lower highlands agro ecological zone II thus high yield potential and favourable climate for livestock keeping and sheep rearing, the wetland provides good grazing ground especially during the dry season (Government of Kenya, 2002).

A study conducted in 2007 identified seventeen plant species that were sampled in the Manguo wetland basin (Appendix 1). They were all grass and herbaceous species. Manguo wetland is broadly classified into three ecological units: the open water, sedges and semi-flooded grasses (marshes) and the dry grass area.

The open water area has greatly reduced in size and hence volume and this could be due to soil erosion which has led to sedimentation of the wetland thus reducing the water level coupled with climate change and water extraction. The eastern side of the wetland is the only portion remaining with open water pools which could be as a result of the closing of the south-eastern outlet leading to greater retention of water.

The open water is also highly polluted along the edges with plastic bags, clothing and shoes which is evidence of dumping and the garbage that is washed down to the water. The open water is muddy in some areas which could be a result of the grazing animals which drink from the shallow points. Some areas of the open water have a green surface which is as a result of algal growth on the water surface.

The open water edges are dominated by reeds and sedges that offer optimum feeding and breeding sites for the birds. Manguo wetland is an important bird habitat for resident and Palearctic migrant species. Between 1993 and 2006 about 56 bird species were identified by the National Museums of Kenya (Appendix 3). During this study a high number of birds were noted, its strategic location along the Nairobi-Nakuru highway makes it a prime area for avian tourism.

The semi-flooded grasses and dry grass area is mainly a grazing site where there is intense grazing of cattle, donkeys, goats and sheep. It is also used as a recreational site especially by organizations such as Nature Kenya, the National Museums of Kenya and schools (primary and secondary) involved in avian related activities and by the local people in form of a play ground for school children, there is a clearly marked football pitch on the northern part of the wetland. The catchment area is covered by trees which have been planted by individual land owners and in some areas looks like a continuous stand and the common species is eucalyptus.

Plate 3.1 shows *Cyperus* species (C. *exaltatus and C. rotundus*) on the fore ground within the wetland and farmlands on the slopes of Manguo watershed with Eucalyptus stands. Other tree species observed were the *Croton, Toona ciliata* (red cedar) and *Pinus* trees.

Plate 3.1: Eucalyptus stands in the background on farmlands in Manguo watershed

3.1.5 Human activities and resource use

The elevation of the wetland respective to the surrounding area discourages irrigation as the wetland is located in a depression; however water is used to water farms on the eastern side. There were several human activities identified and their impacts and ecological significance noted (Appendix 8). Land use around the wetland is mainly small scale farming (beans, carrots, kales, cabbages, potatoes etc) and livestock farming both zero grazing and free range. This could be a source of pollution through use of fertilizers which drain down to the water, the farming system also leaves a lot of bare land thus there is soil erosion leading to siltation of the open water further reducing the water holding capacity.

Water quality of Manguo swamp in 2007 was fairly neutral pH values of approximately 7.03, low concentrations of cations, phosphates and nitrates, a situation attributed to presence of fringing macrophytes that limit nutrient flow into the swamp (Macharia and Thenya, 2007). The swamp is an important source of water for Limuru town and the surrounding rural area mostly through two boreholes located in the southern low flooded area of the swamp. There was also extraction of water by locals who come and fetch water directly from the swamp for sale especially during the dry season as observed in September and October 2011.

Soil harvesting which is a very destructive land use form had occurred leaving large open pits. They were filled with water and were dangerous especially as the area was used a play ground and grazing ground (Plate 3.2).

Plate 3.2: Manguo basin showing a soil excavation pit.

The wetland has a thin layer of grass overgrazed by livestock; the open pit has some water which is from seepage indicating a high water table. The land around the wetland slopes gently and is divided into individually owned parcels.

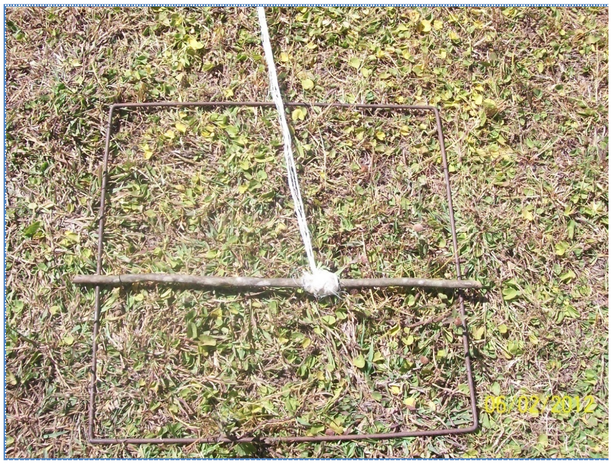
3.2 Materials and methods

3.2.1 Study design and selection of sampling points

Understanding spatial and temporal patterns of species diversity is a crucial topic in ecology and conservation biology, and one approach to partition species diversity is to define α-diversity as within-habitat diversity, β-diversity as a measure of between-habitat diversity (within landscape) and γ-diversity as within-landscape diversity (Magurran, 2004). The α-diversity was the main focus of this study of the wetland vegetation.

The study area measured 7.5ha (300m by 250m). Line transects were placed across the wetland from the open water to the edge of the wetland. Quadrats were used to sample at regular intervals of 0.5m from the open water in the four compass directions North, East, South and West giving 48 plots of 0.5m by 0.5m (Figure 3.3). The sampling quadrats were 0.5m×0.5m ($0.25m^2$).

Systematic sampling was the preferred method of sampling because of the general similarities in vegetation zonation into observable ecological units. This reduces sampling errors because the major sources of error can be recognized before sampling. The sampling interval was reduced so as to reduce variation within the zones. The units were determined according to the physiognomic homogeneity.



Example of a sampling site, a 0.5m * 0.5m quadrat was used to collect the vegetation data.

Plate 3.3: A 0.5*0.5m sampling quadrat

For the palynology samples, the sampling point selected was dependent on the sedimentation level of the basin. This dependence on depth meant that the sampling point was chosen after several areas were sampled with the testing rod, the deepest point was chosen and the sediment retrieved using a Russian corer.

Plate 3.4: Determination of coring point at Manguo wetland

Using a testing rod several areas were surveyed until a suitable spot was found. The above spot chosen was at the sedge area, mainly comprising of *Cyperus* species.

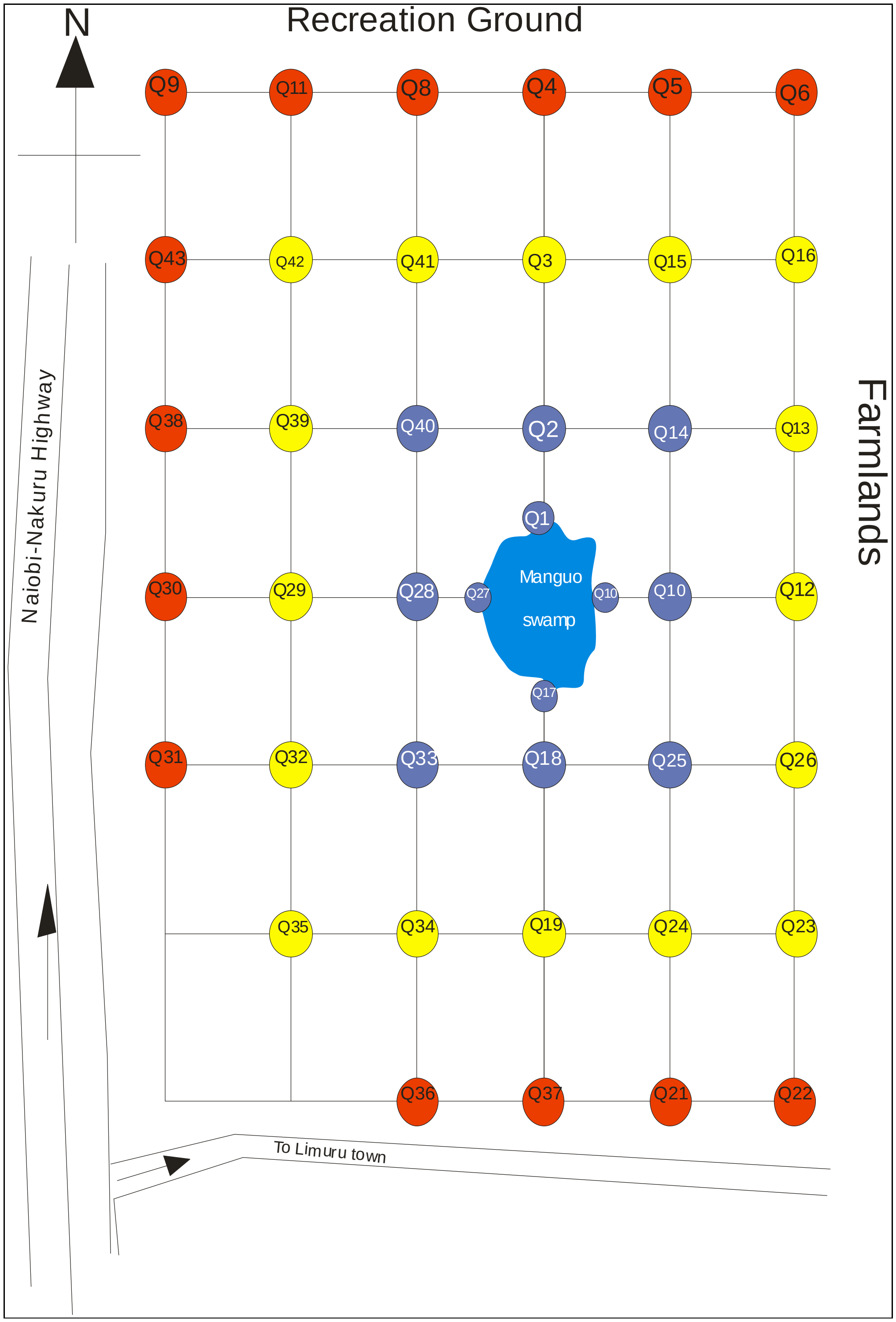


Figure 3.3: Sampling Design

Zone A	Zone B	Zone C

Q—— Q 50cm

3.2.2 Vegetation sampling and analysis

Vegetation was sampled using quadrats measuring $0.25m^2$ (0.5m×0.5m), the quadrats were systematically placed along transects at intervals of 50m. From each quadrat the species present were identified, individuals counted, their cover measured (estimated). The number of individuals of each species was recorded so as to calculate the species abundance, density and frequency. Species were identified by use of reference books (Agnew 1994, Beentje 1994) and also with the help of the University of Nairobi herbarium staff.

3.2.3 Soil sampling and analysis

3.2.3.1 Collection of soil samples

At each selected sampling point (quadrat), two soil samples (top and sub soil) were obtained by the use of a soil corer which had markings that helped identify the depth at which the sample was being collected. The samples were then stored in sturdy brown paper bags or polythene bags if wet and labelled before transportation and analysis in the laboratory. The general equipment for the soil sampling included: soil corer, plastic bags, brown paper bags and plastic jars.

In the lab the soil samples were air dried and sieved through a 2mm mesh. The fraction passing through the sieve was the fine earth fraction. The fraction remaining in the sieve (if any) was the coarse material. Both fractions were weighed and expressed as a percentage of the total soil: for example, the fine earth may be 85% and the coarse material 15%. In many soil samples there was no coarse material, in which case the fine earth was 100% of the soil. The coarse material, if any, was weighed and described but no further analysis was carried on it. The samples were weighed using a weighing scale. An analysis of the essential elements was carried out on the fine earth fraction only.

3.2.3.2 Soil pH

pH or the hydrogen ion concentration is an important chemical component of a habitat. pH measurements should be done as soon as possible after sample collection as other chemical changes in the sample can quickly alter the pH by as much as 0.5.

Results of the determination of the pH of a soil extract are referred to as soil pH but should be stated as the pH of 1:1soil water extract or whatever ratio is used. PH at which the nutrients are available for plant uptake is pH 5.6-7.5

The pH of the soil was determined, using a pH meter and glass electrodes. The pH as measured in the laboratory is affected to a slight extent by the ratio of soil to water or solution used. This was done using one part of soil to 2.5 parts of water to allow better contact between the electrodes and the soil/water suspension.

The soil/water mixture was allowed to come into equilibrium for 25 minutes with stirring or shaking at intervals, and then the suspension was allowed to settle so as to give a layer of fairly clear supernatant water above a lower layer containing soil in suspension. The pH meter was standardized by use of a buffer solution before determination of sample pH. The electrodes were then lowered into the partly settled suspension, and the pH read on the meter (Black, 1965).

3.2.3.3 Soil salinity and conductivity

Salinity is the total amount of soluble salts in a water or soil solution. One basic measure of salinity is the ability of the solution to conduct an electric current for ions are great conductors.

The meter was standardized and the temperature correction dial adjusted, then 100ml of water was filtered if the water was turbid and the conductivity meter electrodes inserted into the sample. The readings were recorded in µmho/cm. Unit of measurement of salinity was ppm of potassium chloride (KCl) or sodium chloride (NaCl) and for conductivity was µmho/cm.

3.2.3.4 Soil organic matter content

Organic matter content of the soil was determined using the Walkley-Black method which measures the carbon in the organic matter by oxidizing it and multiplying the carbon content by a factor reflecting the average carbon content of the soil organic fraction.

The formula for oxidation of carbon is:

$$2k_2Cr_2O_7 + 8H_2So_4 + 3C = 2Cr_2(So_4) + 8H_2O + 3Co_2$$

For sample preparation the soil sample was ground and passed through a 0.5mm sieve to increase homogenization of sample and facilitate oxidation. A sample of soil weighing 0.5g was put into an Erlenmeyer flask and 10.0ml of 1N potassium dichromate added with the use of a pipette while swirling to make sure all the sample came into contact with the reagent.

Concentrated sulphuric acid (36N) was measured (20ml) in a measuring cylinder and poured in a steady stream into the center of the soil-dichromate mixture. There was an immediate reaction including some bubbling and production of a considerable amount of heat so the mixture was allowed to cool for about 20 minutes.

Distilled water was added to bring the volume to 200ml then 5.0ml 85% orthophosphoric acid (H_3PO_4) and 5.0ml diphenylamine sulphonate indicator were added. This was titrated with 0.5N ferrous sulphate and as the end point approached the turbid dark blue colour became greenish and a clear pale green quite sharply at the end point.

The percentage of the carbon in the soil was calculated using the following formula which takes into account that 1ml of N dichromate oxidizes 3mg of carbon:

$$\% C = \frac{(m.e\ dichromate - m.e\ FeSo_4) \times 0.3}{Weight\ of\ soil\ in\ grams}$$

3.2.3.5 Soil texture using the hydrometer method of soil mechanical analysis - soil texture analysis (Hinga, 1990)

An air-dried soil sample measuring 51.0g was measured; passed through a 2mm sieve and transferred to a "milkshake" mix cup (a 51.0g air-dry sample represents approximately 50.0g of oven-dry soil). A solution of 50cc sodium hexametaphosphate and 100cc of distilled water was added and the mixture was stirred with a stirring rod and sample left to set for 30 minutes.

The soil suspension was stirred for 15 minutes using the multi-mix machine then transferred from the cup to the glass cylinder. With the hydrometer in the suspension, distilled water was added to the lower blue line, the volume was then 1130cc. Upper line (1250cc) was used when 100 grams were used, the hydrometer was then removed.

The top of the cylinder was covered by hand and inverted several times until all soil was in suspension. The cylinder was then placed on flat surface and time noted. The soil hydrometer was immediately placed into the suspension and slid slowly into suspension until hydrometer was floating. The first reading on the hydrometer was taken at 40 seconds after the cylinder was set down.

The hydrometer was removed and temperature of suspension measured with a thermometer and recorded. After the first hydrometer reading the suspension was left to stand for 3 hours and a second reading taken along with the temperature of the suspension. The first reading measured the percentage of silt and clay in the suspension. The second reading indicated the percentage of 2 micron (total) clay in the suspension.

Results were corrected to a temperature of 68˚ Fahrenheit where for every degree over 68˚F, 0.2 was added to hydrometer reading before computation and for under 68˚F 0.2 was subtracted from hydrometer reading. Extremes such as 50˚C or 100˚C were avoided and 2.0 were subtracted from every hydrometer reading to compensate for the added dispersing agent.

Sample calculation was carried out as illustrated in the following example:

1 a. Hydrometer reading at 40 seconds, H_1=18

b. Temperature at 40 seconds, T_1=75˚F

2 a. Hydrometer reading at 3 hours, H_2=8

b. Temperature at 3 hours, T_2=63˚F

3. Temperature correction added to hydrometer reading = 0.2 (T-68) where T=degrees/Fahrenheit.

4. Salt correction added to hydrometer reading = -2.0

SAND = $100.0 - [H_1 + 0.2\,(T_1 - 68) - 2.0]^2 = 65.2\%$

CLAY = $100.0 - [H_2 + 0.2\,(T_2 - 68) - 2.0]^2 = 10.0\%$

SILT = $100.0 - (\%\,sand + \%\ clay) = 24.8\,\%$

The percentages by weight of sand, silt and clay for the soils used were tabled showing individual composition for each soil sample collected at different positions.

3.2.3.6 Soil nitrogen

Nitrogen is one of the major elements required for life, it is abundant in the atmosphere as N_2 but must first be converted into ammonia, and nitrate or some organic form before it can be used by organisms. Most of the nitrogen in the soil occurs in the organic matter (humus) of the soil because in organic combination it is not available to plants.

The most commonly used method of determining total nitrogen is a wet digestion method in which the sample is digested for several hours with concentrated sulphuric acid so that all the nitrogen is converted to ammonium. This method was first described by J. Kjedahl in 1883 and the simplicity of the method and speed and completeness of the conversion of N to NH_4 have resulted in the fact that the basic method is still the most widely used today, though several modifications have been introduced.

The Kjedahl method gives very satisfactory, reproducible results provided that the digestion procedure is continued long enough. Almost all combined forms of N are converted to NH_4, though the nitrite and nitrate in the soil is not included unless the method is modified.

The standard Kjedahl method analysis involves two steps:

1. Digestion of the sample to convert N to ammonium.
2. Determination of the ammonium in the digest.

The Kjedahl method was used for the determination of total nitrogen in the soil samples. The samples were digested with a potassium persulphate solution in an autoclave. Subsequently, nitrates and nitrites were reduced to ammonium with Devarda alloy and ammonium determined colorimetrically.

If a 10.0g sample was used to give 250 ml of digest from which a 50ml aliquot was distilled, then the percentage N in the sample was:

$$\frac{Ml\ acid \times 5 \times 0.14}{Weight\ of\ soil\ in\ mg} = N\%$$

Assuming a reading of 30ml of 0.01N acid and 10.0g of soil, then the calculation was:

$$\frac{Mg\ N}{Mg\ soil} = \frac{30 \times 5 \times 0.14}{100} = 21\%$$

3.2.3.7 Colorimetric determination of soil phosphorous.

Determination of phosphorous was carried out through the method described by Okalebo *et. al.*, 2002. Monobasic potassium phosphate (KH_2PO_4) weighing 0.4393g was put into a 1 litre volumetric flask and 500ml of distilled water added and shaken until the salt dissolved. It was then made to volume with distilled water and 5 drops of Toluene added to diminish microbial activity. This solution contained 0.1ml p/ml (100ppmP or 100µg P/ml).

A measure of 5ml of the 100ppm stock solution was put into a 100ml volumetric flask using a pipette and made up to volume so as to obtain 5µg P/ml. A 5.0g sample of soil was weighed into a 100ml or 125ml extracting tube and 50ml of Double Acid reagent added accurately with a pipette. The tubes were stoppered to prevent any leakages and placed horizontally in a rack on a mechanical, reciprocating shaker for 15 minutes.

The soils were filtered through Whatman No. 42 filter paper (filter speed: medium) collecting the filtrate in specimen bottles. It was necessary to shake the extracts every time just before transferring them into the filter paper rather than simply decanting off the supernatants. The filter papers were not filled to the brim and this ensured that no soil was behind the filter papers.

If the filtrate contained soil particles it was filtered again into a clean specimen bottle using a clean filter paper preferably Whatman No. 42 (filter speed: slow). If soil particles are present in the filtrates they will interfere with the analysis.

A set of standard P solutions was prepared by pipetting 0, 1, 2, 3, 4 and 5ml of the ppm secondary standard into 50ml volumetric flasks. To each of the flasks 5ml Double Acid was added followed by 20ml of distilled water. Then 8ml of reagent was added to each flask and immediately made to volume with distilled water and thoroughly mixed thereafter.

It was allowed to stand for 15 minutes before taking the reading (absorbance) with the spectrophotometer. The data was used to draw a calibration curve by plotting absorbance (V-axis) against P concentrations of the standards (H-axis). The standard curve was used to determine P concentrations in the soil to the corresponding P concentrations.

One ml aliquot of the 0 to 30cm depth soil extract was pipetted into a 50ml volumetric flask and approximately 25ml of distilled water added followed by 8ml of reagent B and immediately followed by distilled water to the mark and mixed thoroughly then allowed to stand for 15 minutes before taking the readings.

The concentrations of P in the filtrates were used to calculate the P status of the original soils by taking into account the weight of soils used, the volume of the extracting (Double Acid), the final volume of the (coloured) solution and the aliquot of the filtrate taken (i.e. pipette for analysis).

3.2.4 Water sampling and analysis

3.2.4.1 Water sampling

Water samples were collected from two pools; this is because when the water level rose the permanent pool spilled over and flowing out through a track formed by the grazing animals. It settled at a point with a lower elevation, when precipitation is really high the Manguo water is in two open water bodies. The second temporary pool was smaller in depth and width than the main one and the water samples were collected using 500ml glass bottles just under the water surface very slowly so as to prevent it from mixing with atmospheric air. After completely filling the 500ml glass containers they were stoppered.

3.2.4.2 Water pH

The ph was measured using a portable ph meter, which gives an accurate and quick measure of the pH. It contains a hydrogen sensitive electrode called the indicator electrode which was dipped into the water and the reading recorded. Temperature at which pH was recorded was also noted.

3.2.4.3 Water temperature

At each sampling point the thermometer was immersed into the water a few centimeters below the surface and temperature recorded. This was done from three locations at each sampling point and the average mean surface temperature calculated.

3.2.4.4 Water quality

The water samples were collected just under the surface very slowly so as to prevent it from mixing with atmospheric air. After completely filling the 500ml glass containers they were stoppered.

The water samples were then transported to National Agricultural Laboratory (NARL) at the Kenya Agricultural Research Institute (KARI) for analysis of the following parameters: sodium, potassium, calcium, magnesium, carbonates, bicarbonates, manganese, iron, and zinc. They are important aspects when determining the water quality for different uses and the water status.

3.2.5 Determination of historical vegetation changes through palynology

Palynology is the study of pollen grains and spores from higher plants and cryptograms. In this study the proxy used was the pollen grains; use of pollen grains is one of the most widely applied quaternary research tools.

3.2.5.1 Site selection and coring

The sampling point was selected after determining the best coring point by use of a depth determining pole. The soil core was then collected from the field by use of a 5cm diameter Russian soil corer from parallel points with overlapping sections so as to minimize contamination and transferred into 50cm PVC pipes sectioned in half.

3.2.5.2 Soil core description and preparation

The core sections (Plate 3.5) were then lithologically and stratigraphically described and wrapped with aluminium foil before transporting to the laboratory for analysis. A 225cm core was retrieved and sampling was done at 10 cm intervals thereby giving 21 samples. At each point 1cm^3 of soil was retrieved and put into Pyrex test tubes for analysis.

3.2.5.3 Pollen analysis

The pollen samples were processed according to the procedure described by Moore and Webb in 1978 where the pollen grains are extracted from the soil sample using strong acids and alkalis to remove mineral and organic matter. The samples were then filtered through a porous membrane or sieved to isolate the particular size fraction of pollen.

The pollen was then stained for better visualization and mounting the pollen residue on microscope slides for analysis (Horrocks 2004). Pollen is highly resilient and withstands the extraction process well.

Plate 3.5: A 50cm soil core section, minor changes in sediment colour are visible

The retrieved soil core changed in colour, this was a top section rich in organic matter that was very dark organic matter and slowly lightens. The core was laminated by streaks of reddish brown bands and organic matter particles such as roots.

3.2.5.4 Pollen identification

The pollen was identified by microscopic visualization using an Olympus microscope to determine the pollen types using the highest magnification necessary (usually ×40). This was done until 250 or more grains were counted. Where the count was lower than 250 grains two or more slides were counted.

The wide variety of sizes shapes and surface characteristics of pollen helped with the identification process using reference slides from the National Museums of Kenya and reference books (Bonnefille 1968, Beentje 1994, Marchant 1997). The pollen was further analyzed by matching the identified pollen in a forensic sample to pollen in a known geographic location.

3.2.6 Data analysis

By coming up with a vegetation inventory of the wetland and assessing the soil and water characteristics, the data collected were represented graphically to visually display the results. The soil and water quality results were tabulated and graphically displayed so as to easily show the individual soil and water characteristics of the wetland and also in relation to the vegetation distribution.

Vegetation analyses were carried out to calculate abundance, density, frequency of each species. Vegetation diversity across the wetland was calculated and compared using Shannon-Weiner Diversity index while richness was calculated using the Margalef index. The Sorenson index was also calculated to determine the similarity between the wet and dry season samples.

3.2.6.1 Vegetation data analysis

Species abundance

Species abundance is the number of species sampled and their total numbers. The species sampled were listed and their numbers noted. The species abundance was also used to conduct analysis of variance between and within the zones and two periods.

Sample similarity

A similarity index was calculated using species abundances to compare the species collected during the wet period and those collected during the dry period. Comparison of the two samples was necessary because in plant ecology similarity of samples is expected to be representative of communities (Moravec 1973) and thus one can infer if wetness had any impact on the plant community.

There are two similarity indices that are widely used in vegetation studies to evaluate similarity of samples (Leps & Smilauer, 2003) i.e. the Sorensen and the Jaccard coefficient. Using the Sorenson coefficient (Sorensen, 1948) it was possible to determine how similar the wet and dry period samples were using the formula:

$$S = \frac{2a}{a+b+c}$$

a _ number of species present in both sample A and B.

b _ number of species presents in sample A only.

c _ number of species present in sample B only.

Density

Density is the number of individuals per unit area sampled and is calculated by dividing the number of individuals by the total area sampled.

Density = $Total\ number\ of\ species\ \div Total\ area\ sampled$

Total area is $0.5 \times 0.5 \times 43 = 10.75$

Relative density = $(Density\ value\ of\ A \div Total\ density\ for\ all\ species) \times 100$

A = Individual species sampled.

Density calculations are important in determining how many individuals of each species are present relative to all of them in the particular study.

Frequency

Frequency is the probability of encountering an individual and is presented as percentages.

Frequency species A = $\frac{Number\ of\ sampling\ points\ in\ which\ A\ occurs}{Total\ number\ of\ sampling\ points}$

Relative frequency species A = $\frac{Frequency\ of\ species\ A}{Total\ frequency\ of\ all\ species} \times 100$

Frequency values tell us whether or not a species was encountered and how many times relative to all the other species.

Species diversity

Species diversity was calculated using the Shannon - Weiner diversity index.

$H^i = -\sum PiLogPi$ Where, $P_i = {}^{ni}/_{N}$

Pi is the proportion of the total number of individuals occurring in species I.

Species richness

Species abundance is the number of individuals of each species. This is a useful measure of species diversity if the study area can be successfully delimited in time and space and the constituent species identified and enumerated. The species richness across the wetland was calculated using the Margalef index of species richness (Margalef, 1958) whose formula is: $D_a = (s-1) / \log N$ S = Number of species. N = number of individuals of all species.

It is used to calculate the species richness of an ecosystem taking into account the number of species present or counted and the total number of individuals. However it cannot be used to compare or differentiate between two communities if they have almost the same number of species and if the number of individuals is low.

The chi-square (X^2) statistic was used as a measure of how much an observed sample distribution of nominal-scale data differed from a hypothesized distribution. It uses the actual frequencies observed and if $X^2_{\text{calculated}} > X^2_{\text{tabulated}}$ then H_o was rejected. (Zar, 2010)

Effect of seasonality and zonation on species abundance

Analysis of variance which is a statistical technique that examines the several sources of variation among all of the data in an experiment by determining the sum of squares of deviation from the mean from each source was applied to determine whether the seasonality and zonation had any significant impacts on the species abundance. Conclusions were made after formulating and testing a hypothesis.

If $F_{\text{calculated}} > F_{\text{tabulated}}$ then H_o was rejected.

A two factor analysis of variance followed by unequal N HSD post hoc tests were carried out to determine whether there was a significant difference in species composition and abundance across the wetland and between the wet and dry period samples.

Species distribution

A multivariate analysis was carried out to search for distributional overlaps between the plant species sampled and the soil variables. First, an unconstrained ordination (i.e. detrended correspondence analysis, DCA) was carried out to provide the basic view of the compositional gradient in the data; the ordination transformation has a logarithmic nature.

Constrained ordination was then carried out so as to directly extract the variation that is explainable by the measured soil variable. This was followed by Monte Carlo permutation performed to determine significant variables that influenced the species distribution. This was carried out using CANOCO 4.5 statistical programme.

3.2.6.2 Soil and water data analysis.

The soil and water parameters determined were tabulated and analysed using the Excel program. The parameters were then compared and graphed so as to show relationships and trends between the hydrology, soils and vegetation this was done using STATISTICA 8.0. Ordination (DCA) was carried out using CANOCO 4.5 to summarize community patterns and compare suggested gradients with the vegetation distribution. Mann-Whitney U test was carried out to determine the difference between the top and sub soil characteristics.

$$U = n^1 n^2 + [n^1[n^1 + 1]/2] - R1$$

3.2.6.3 Pollen data analysis.

A core profile measuring 225 cm was lithologically described and drawn to show the changes in soil along the profile. Pollen data was captured using Excel and analysed using TILIA program 2.0.b.5 and Constrained Incremental Sum of Squares (CONISS). The totals were calculated and percentages of all pollen, spores, spirogyra and indeterminable grains determined.

The program Tilia 2.0 consists of a suite of programs for the plotting and analysis of stratigraphic data, such as pollen and diatoms and was initially designed for making pollen diagrams, but is useful for many other kinds of stratigraphic data. The data in percentage form calculated in Excel was input into Tilia where the depth against species diagrams of the pollen were plotted and different analysis depending on requirements carried out.

The Tilia file was then analysed using CONISS which carried out Constrained Incremental Sums of Squares cluster analysis which groups samples sharing similar values and results arranged in hierarchical order thus the profile was divided into zones giving four zones from the top to bottom of the core. It works by searching the dataset for the two most similar, stratigraphically-adjacent, samples, and combining them. The combination is then treated as a single sample, and the search repeated (Grimm 1987).

CHAPTER FOUR

RESULTS

4.1 Overview of vegetation types around Manguo wetland

The wetland was dominated by herbaceous vegetation particularly the sedges. In the flooded region the main species were the *Cyperus species (C. exaltatus and C. rotundus)*, in the semi flooded region it was *Plantago palmata* while in the dry region it was Kikuyu grass (*Pennisetum clandestinum).* A total of 34 plant species were identified at the Manguo watershed during the study (Appendix 2) and 20 were sampled within the wetland.

The watershed was vegetated by a mixture of herbaceous and woody vegetation with mainly agricultural crops. Most of the Manguo watershed comprised individually owned land that was sub divided into small farms where subsistence farming was carried out. The most common crops grown are maize, beans, kales, cabbages. The farmers also practiced agro-forestry with small plantations of eucalyptus and pine (*Pinus* species) present. There were isolated species of *Croton, Olea* and the red cedar present.

4.2 Plant community structure

A total of 20 species from 12 families and 8 orders were sampled during the study both in the dry and wet period. Families Poaceae and Asteraceae had the highest representation with 6 and 5 species respectively. The first sampling was carried out in October 2011 which was a dry period (as the short October to December rains had not yet started) while the second sampling was carried out in February 2012 just when the short rains stopped and the wetland was still flooded.

Some species collected during the wet period were not present during the dry period (Table 4.1) just as some species sampled in the dry period were not present in the wet period. During the dry period sampling 17 species of plants belonging to 8 orders and 11 families were recorded while in the wet period, 16 plant species sampled belonged to 6 orders and 9 families. Species absent during the dry period were *Ethulia Conyzoides*, *Gnaphalium declinatum* and *Portulaca quadrifida* while the species absent during the wet period were *Sphaeranthus napiera, Pavonia Urens, Laportea alatipes* and *Hagenia abyssinica*.

Application of the Sorenson's coefficient formula on the dry and wet period plant species data revealed that the samples were generally similar (S = 0.79).

$$S = \frac{2a}{2a+b+c} \qquad S = \frac{2\times13}{26+3+4} \qquad \therefore S = 0.788$$

When S = 0 the samples are least similar and when S = 1 the samples are most similar.

Table 4.1: Seasonal comparison of the occurrence of plant species in Manguo wetland

Order	Family	Species names	Authority	Period Dry	Period Wet
Poales	Poaceae	*Pennisetum clandestinum*	Hochst. Ex. Chiov	+	+
		Cynodon dactylon	(L.) Pers	+	+
		Pennisetum purpureum	Schumach 1827	+	+
		Digitaria ciliaris	(L.) Scop	+	+
	Cyperaceae	*Cyperus rotundus*	L.	+	+
		Cyperus exaltatus	L.	+	+
Asterales	Asteraceae	*Dichrocephala integrifolia*	O. Kuntze	+	+
		Sphaeranthus gomphrenoides	O. Hoffm	+	+
		Ethulia conyzoides	(L) Carl Von F.	_	+
		Gnaphalium declinatum	(L.F)	_	+
		Sphaeranthus napiera	L.	+	_
Caryophyllales	Polygonaceae	*Polygonum setaceum*	L.	+	+
	Caryophyllaceae	*Uebelinia abyssinica*	Hochst.	+	+
	Portulacaceae	*Portulaca quadrifida*	L.	_	+
Apiales	Mackinlayaceae	*Centella asiatica*	(L.) Urban	+	+
Oxalidales	Oxalidaceae	*Oxalis corniculata*	L.	+	+
Lamiales	Plantaginaceae	*Plantago palmata*	L.	+	+
Malvales	Malvaceae	*Pavonia urens*	Cav.	+	_
Rosales	Urticaea	*Laportea alatipes*	Gaudich	+	_
	Rosaceae	*Hagenia abyssinica*	Willd.	+	_

KEY: (+) Present **(-)** Absent

Table 4.1 displays the distribution of the species sampled during the wet and dry period and their classification into orders and families.

4.2.1 Species abundance

Species abundance values were used to determine if species abundance was dependent on the season. Chi-square test of the abundance data found X^2 = 2289.17 while the $X^2_{0.05, 15}$ = 24.99. Therefore, this statistical test indicated that species abundance was dependent on season.

Nearly 60% (N=6387) of all the individuals of all species were recorded during the wet period while the rest 40% (N=4272) were recorded during the dry period. The species with the highest abundance were the *Pennisetum clandestinum, Centella asiatica, Cynodon dactylon*, *Cyperus* species and *Plantago palmata*. *Pennisetum clandestinum*, *Cyperus* species, *Cynodon dactylon, Digitaria ciliaris* and *Pavonia urens* had chi-square values greater than 100 (Table 4.2). They contributing the highest seasonal differences in the abundance of plants studied at Manguo wetland.

Table 4.2: Seasonal comparison of plant species abundances sampled at Manguo wetland

SPECIES	N wet	N dry	X^2	V
*Pennisetum clandestinum**	3653	1213	1223.50	1
*Plantago palmata**	44	739	616.90	1
Sphaeranthus gomphrenoides	67	70	0.06	1
Dicrocephala integrifolia	16	5	5.76	1
Polygonum setaceum	55	23	13.12	1
Cyperus spp.*	695	348	114.44	1
Gnaphalium declinatum	32	0	32.00	1
Uebelinia abyssinica	147	292	47.90	1
Centella asiatica	887	560	73.90	1
*Cynodon dactylon**	442	809	107.66	1
*Digitaria ciliaris**	136	9	111.24	1
P. purpureum	33	12	9.80	1
*Oxalis corniculata**	174	5	159.56	1
Portulacca quadrifida	5	0	-	-
Hagenia abyssinica	0	8	-	-
Sphaeranthus napiera	0	2	-	-
Ethulia conyzoides	1	0	-	-
Pavonia urens	0	129	129	1
Laportea alatipes	0	48	48	1
Totals	6387	4272	2708.84	15

N = Number of individuals. X^2 = Calculated chi-square value. V = Degrees of freedom.

4.2.2 Species density

The species densities and relative densities were calculated for both the wet and dry period. The species with the highest densities were *Pennisetum clandestinum*, *Cyperus* species, *Centella asiatica*, *Plantago palmata*, and *Cynodon dactylon.*

During the dry period *Pennisetum clandestinum* had the highest density followed by *Cynodon dactylon* then *Plantago palmata*. Similarly during the wet period *Pennisetum clandestinum* had the highest density followed by *Centella asiatica* then the *Cyperus rotundus* and *Cyperus exaltatus*. The rest had very low densities with some having a density of less than one for example the *Hagenia abyssinica* and *Sphaeranthus napiera* were not encountered during the wet period sampling.

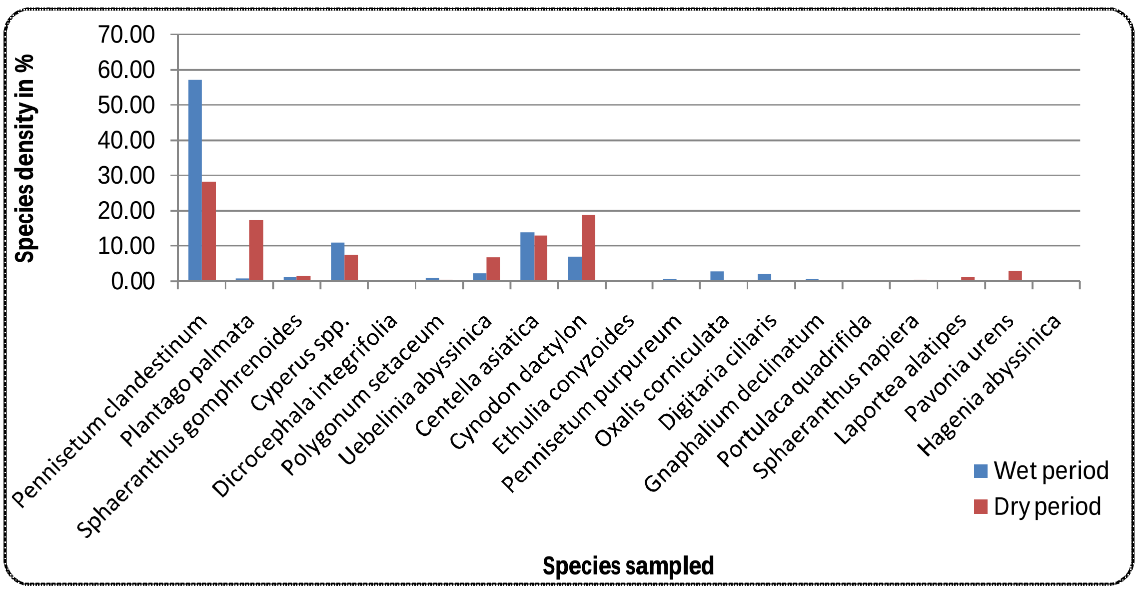


Figure 4.1: Relative densities of species sampled during the wet and dry periods

To determine if seasonality had any effect on the species density a two sample Mann-Whitney test was carried out. The results of the test Mann-Whitney *U* test= 206 < $U_{0.05\,(2),\,19,\,19}$ = 260 revealed that seasonality did not have a significant effect on the species density.

4.2.3 Species frequency

Pennisetum clandestinum had the highest frequency followed by *Cyperus rotundus* and *Cyperus exaltatus* during both the dry and wet periods. Other most encountered plant species were *Centella asiatica*, *Cynodon dactylon* and *Sphaeranthus gomphrenoides.* The relative frequencies were higher during the wet period than during the dry period with 11 species having the higher frequencies during the wet period and a set of 8 species having higher frequencies during the dry period.

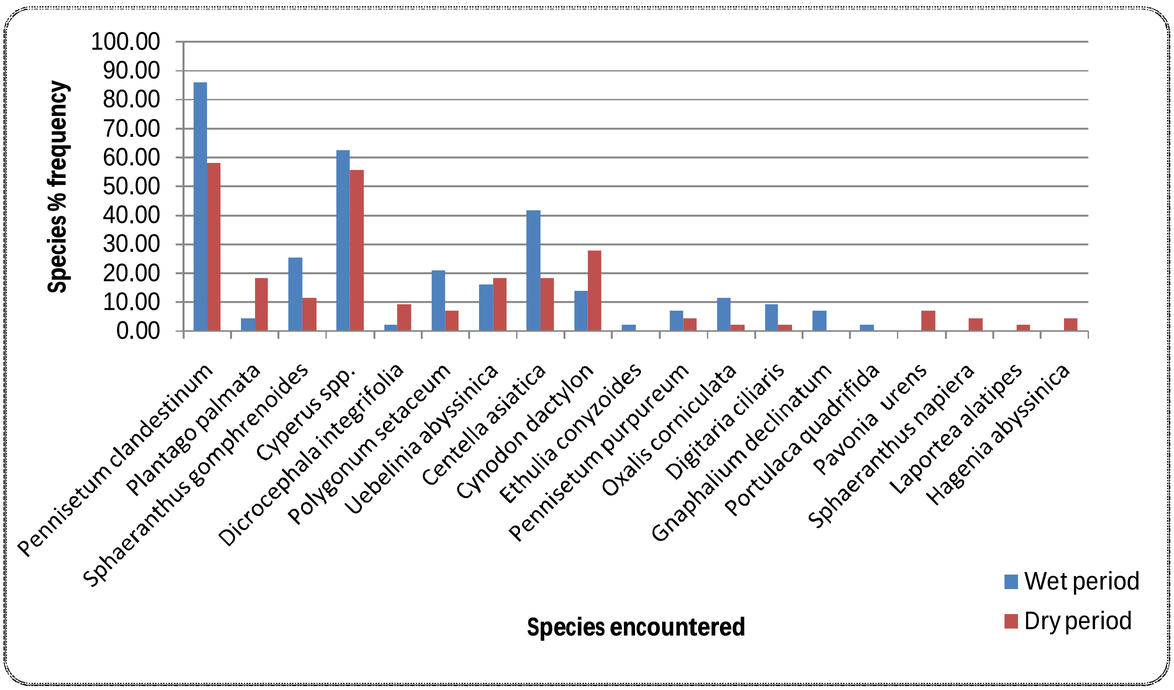


Figure 4.2: Relative frequencies of species sampled during the wet and dry periods at Manguo wetland

A Mann-Whitney test to test if seasonality had a significant effect on the species frequency indicated that seasonality did not have a significant effect on species frequency.

4.2.4 Species diversity

The Shannon-Weiner diversity indices comparing the two samples showed that the wet period (1.05) had higher species diversity than the dry period (0.64).

4.2.5 Species richness

The Margalef index found the species richness in October 2011 was D_a = 4.13 while in February 2012, it was 3.94.

4.2.6 Effect of seasonality and zonation on species abundance

A two factor analysis of variance was carried out to test the effect of seasonality and zonation on species abundance followed by the Unequal N HSD post hoc test. There was no significant impact of seasonality; the difference in species during the dry and wet period could be attributed to the intolerance of some individuals to flooding. The wet period sampling was carried out two months into the rainy season and thus the fast growing macrophytes (*Cyperus* species) increased abundantly and those not adapted to the high water levels disappeared.

To test if zonation had a significant effect on the abundances the $F_{calculated} < F_{tabulated}$ in all instances. There was therefore no significant impact of zonation on abundance. Zonation was based on observed water levels. Zone A had the highest water levels (above 30cm) and zone C had the lowest water levels (<7cm) then the highest difference was expected to be between zones A and C. To determine if there was an interaction of seasonality and zonation, the greatest interaction of seasonality was during the dry period in zone C but even this interaction was not significant.

4.2.7 Species distribution

Detrended correspondence analysis (DCA) was first carried out on the species data to display the species distribution on the landscape. The gradient displayed by species and sites on biplots are used indirectly to attribute distribution to environmental factors.

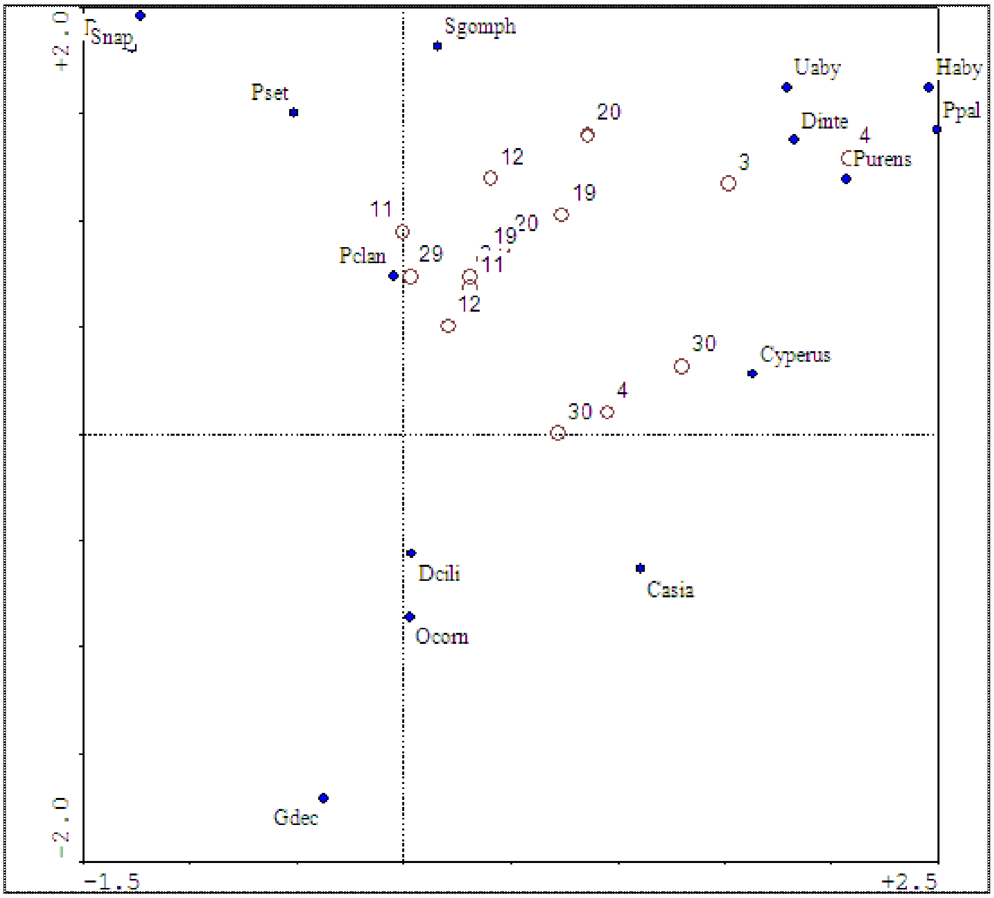


Figure 4.3: Detrended correspondence analysis showing species distribution

The first axis (X) explained the greatest variance of 43% followed by the second axis explaining 10%. Close clustering of species at the top of Figure 4.3 indicated that they were influenced by similar factors. *Digitaria ciliaris* and *Oxalis corniculata* were grouped together. Other species clustered together were *Hagenia abyssinica* and *Plantago palmata* were also influenced by the same factor, similarly so were *Uebelinia abyssinica, Dicrocephala integrifolia* and *Pavonia urens.*

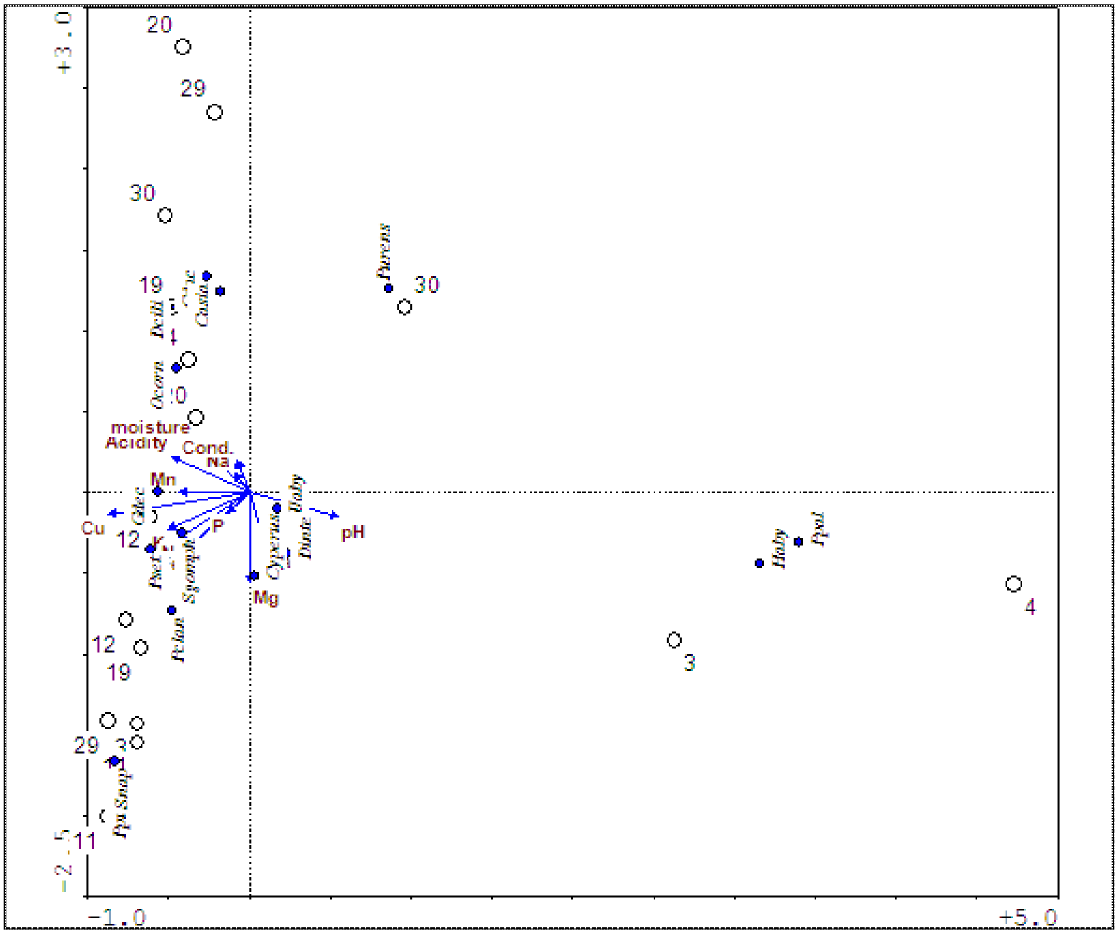


Figure 4.4: CCA of plant species-environment relation in Manguo wetland

Canonical correspondence analysis (CCA) where variation is directly extracted and explained by the measured soil properties was carried out after the DCA analysis. The first axis explained 42.70% while the second axis 22.70%. *Uebelinia abyssinica*, *Dicrocephala integrifolia* and *Cyperus* were highly influenced by Ph levels, while *Gnaphalium declinatum* and *Pennisetum clandestinum* were highly influenced by copper levels (Figure 4.4). Copper, potassium and Ph were found to have the highest influence on the species distribution.

4.3 Soil physical and chemical characteristics

The pH of the wetland soil ranged between 5.07 and 5.89 which are medium acidic. The top soil samples at all the sampling points were more acidic than the sub soil samples and there was a drop in pH from 7.03 recorded in 2007 implying that the wetland soils had gradually become more acidic.

The southern and western parts of the wetland had higher pH than the northern and eastern parts. The southern area bordered the main road to Limuru while the western area bordered the Nairobi-Nakuru highway. The eastern region borders the farmlands and the northern area borders the recreational ground.

For soil pH, it was determined that there was a significant difference in the median pH values of the top and sub soil samples (Mann-Whitney U=54 > $U_{0.05, 8, 8}$ = 51). In all the samples the top soil samples were more acidic than the sub soil samples.

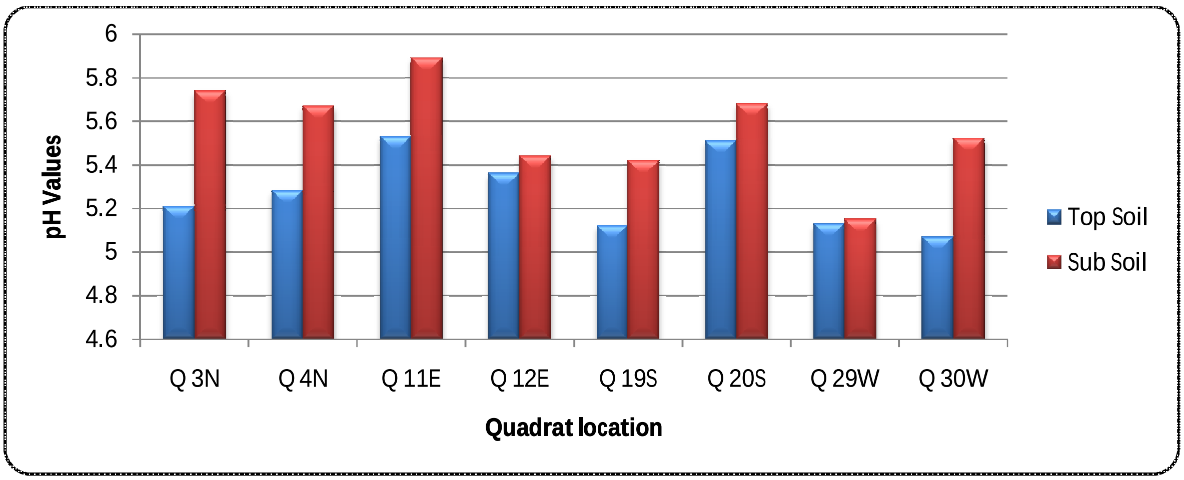


Figure 4.5: Soil pH values of Manguo wetland

All the soil pH values ranged between 5.0 and 5.9, which is strongly acidic to acidic. The Q29 with the lowest pH was located on the west of the open water which was partially flooded and dominated by sedges.

To determine soil quality, the macro and micronutrient levels were analysed and tabulated, the nutrient levels were found to be present at levels suitable for agricultural purposes according to KARI. The Mann-Whitney U test was carried out to determine the differences in the macronutrient levels in the top and sub soil samples. These showed significant differences $U_{0.05, 8, 8}$ = 51.

Macronutrients

The macronutrients analysed were carbon, nitrogen and phosphorous (Appendix 10a).

a. Organic carbon and nitrogen

To the north of the wetland which was flooded, the organic carbon levels were found to be adequate in the top soil (3.2%) but low in the sub soil (1.22%) sample near the open water i.e. quadrat three which was flooded and in a predominantly sedge area. However it was moderate (2.96%) at the sample further up north at quadrat four which was partially submerged and a mixture of sedge and tall *Pennisetum* grass. Towards the East of the open water the organic carbon levels were also adequate at the points near the water (4.36%). However, the sample from quadrat twelve which was in a completely dry area and was dominated by grasses was different. The top soil samples had higher (8.02%) than the sub soil (0.97%). The soils towards the south of the wetland had adequate organic carbon levels with one top soil sample having a high organic carbon level Q20-5.55%. The western side of the wetland was completely submerged and had adequate levels of organic carbon levels (2.30%-2.44%) however the sub soil samples had low levels (0.89%-1.68%) of the organic carbon.

The nitrogen levels were higher in all top soil samples than sub soil samples except in Q19 (0.18%-0.25%). The levels were considered adequate with the east and south of the wetland registering the highest levels within the 0.11-0.80% value range.

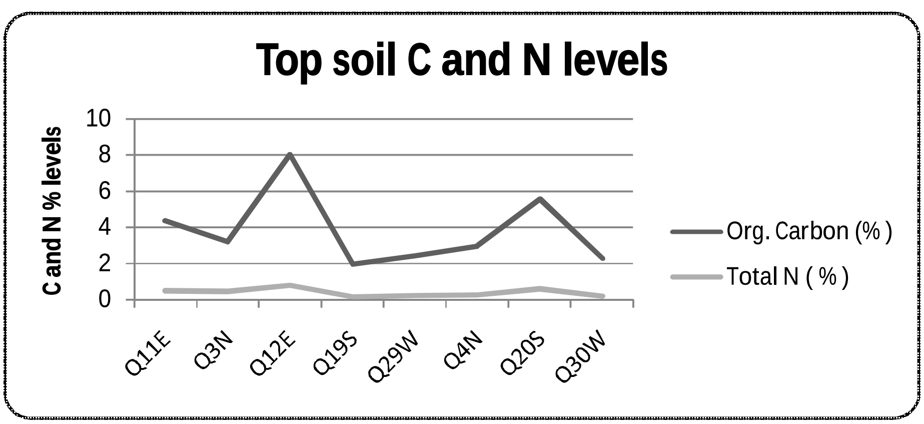


Figure 4.6: Top soil organic carbon and nitrogen levels in the Manguo wetland

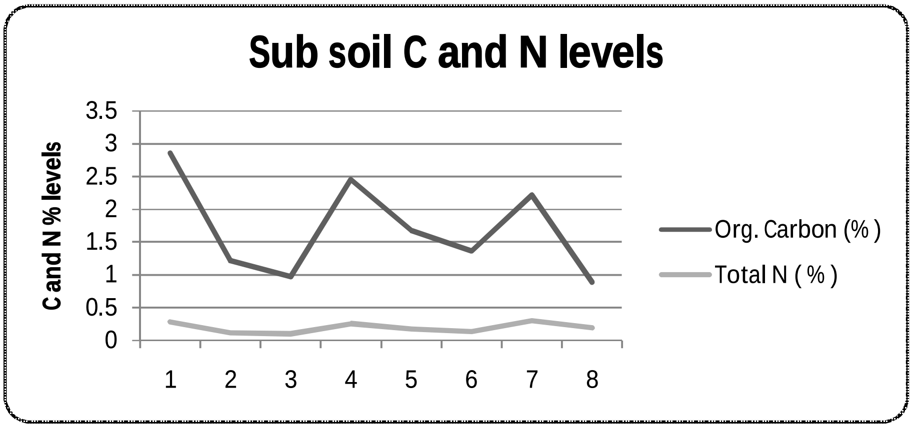


Figure 4.7: Sub soil organic carbon and nitrogen levels in Manguo wetland

Wide C: N ratios (Figure 4.6 and Figure 4.7) i.e. C>N lead to the immobilization of nitrogen. Calculated Mann-Whitney U value for organic carbon was 57, meaning there was significant difference in the organic carbon levels between the top and sub soils as calculated U > tabulated U. While the calculated U for total N was 53, showing a similar result that there was a significant difference in the total % nitrogen between the top and sub soil samples.

b. Phosphorous and potassium

North and west of the wetland the soils had adequate levels of phosphorous (22ppm-51ppm) however one north top soil sample (Q4 = 26ppm) located in a flooded area and one east sub soil sample (Q11 = 23ppm) also located in a submerged area dominated by sedges had low phosphorous levels. The potassium was at adequate levels at all points sampled towards the north (0.68me% - 1.38me %) and high at all samples from the eastern side (1.26me%-2.08me %) of the wetland which was drier than most of the wetland. All samples from the south of the wetland had adequate phosphorous levels (30ppm-60ppm) and high potassium levels (1.3me% - 2.08me %) where sample from quadrat nineteen was from a submerged area mainly sedges and sample from quadrat twenty was from a dry area mainly grasses. The eastern side of the wetland which was highly flooded and mainly sedges also had adequate phosphorous (23ppm-63ppm) and potassium (1.26me %- 2.08me %) levels.

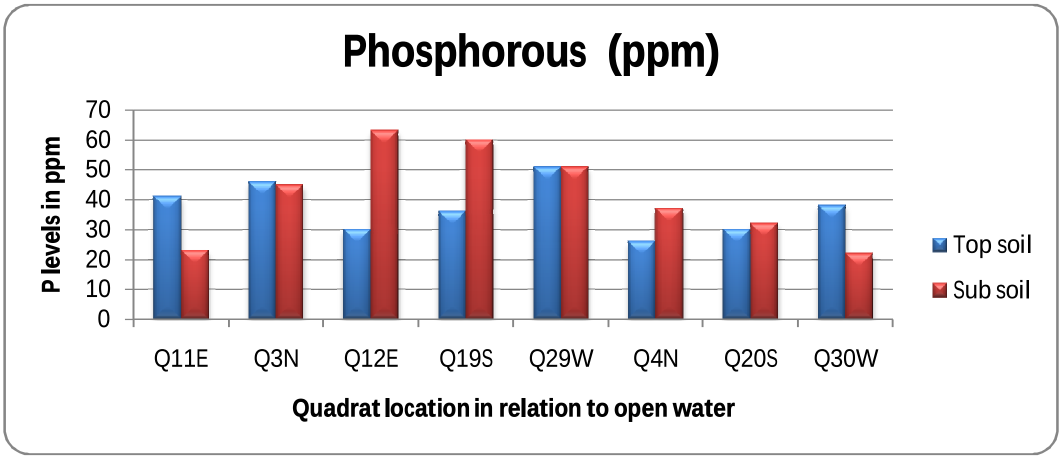


Figure 4.8: Soil Phosphorous levels at Manguo wetland

There was no significant difference in the phosphorous levels in the top and sub soil samples as calculated U < tabulated U. Calculated Mann-Whitney $U = 37 < U_{0.05, 8, 8} = 51$.

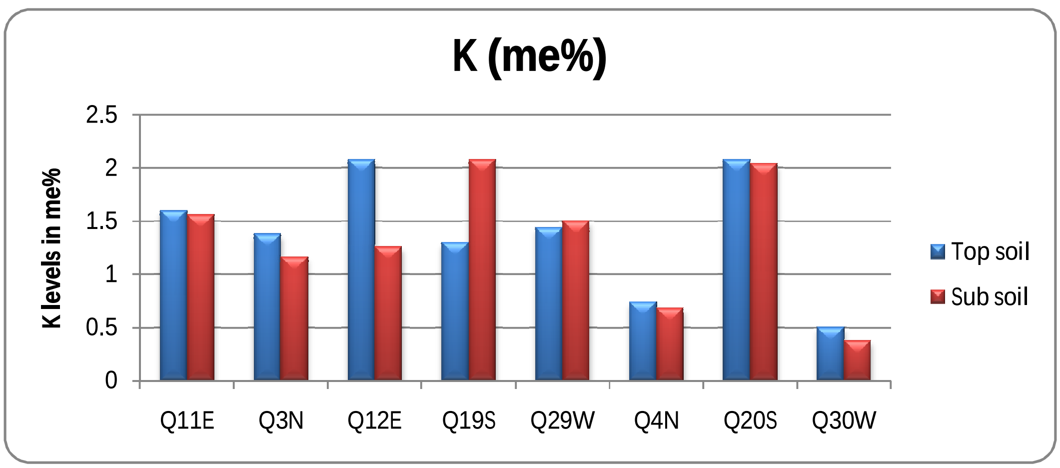


Figure 4.9: Soil potassium levels at Manguo wetland

There was no significant difference in the potassium levels between the top and sub soil samples as the calculated Mann-Whitney $U = 37 < U_{0.05, 8, 8}$ which was 51.

The P levels were lower in most of the top soil samples than in the sub soil samples which could be caused by leaching down of the nutrients. However, the K levels are higher most of the top soil samples than in the sub soil samples.

Micronutrients

The micronutrients sampled were calcium, magnesium, manganese, copper, iron, zinc and sodium all of which are important for plant nutrition (Appendix 10b). They were available at levels considered adequate for agriculture except iron, copper, magnesium, zinc. Iron had very high levels ranging from 125-1569 ppm throughout the wetland; Copper and Zinc were present in low levels (Cu=0.74-0.95me %, Zn=2.18-3.44ppm) in the sub soil samples from the North (Figure 4.11). Magnesium was also adequate (1.5me %- 2.52me %) in all the soil samples except the most western sample which had low levels in both top (0.11me %) and sub soil (0.17me %) samples, the same sample also had low zinc levels in the top soil sample (3.23ppm).

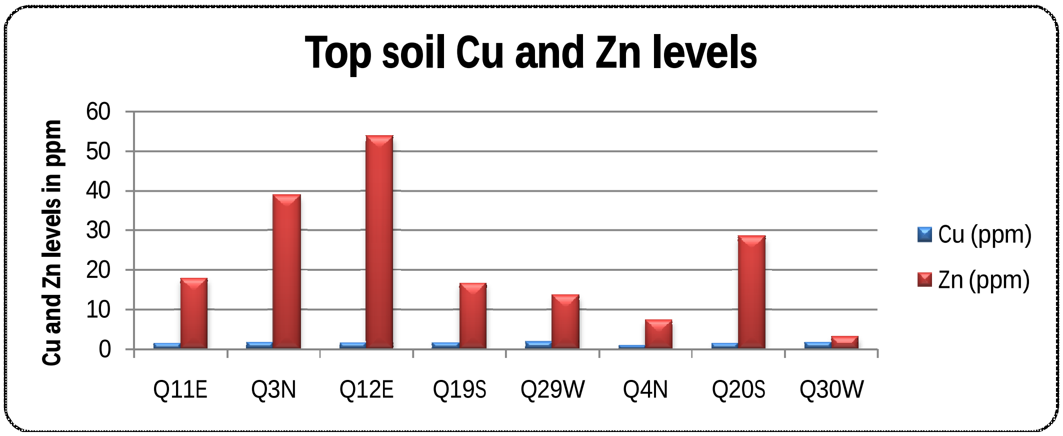


Figure 4.10: Top soil copper and zinc levels in parts per million (ppm)

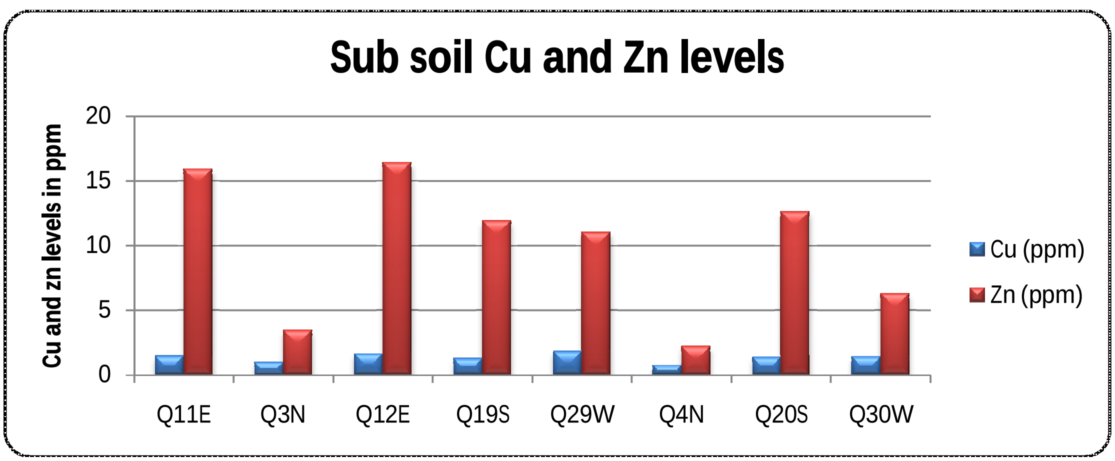


Figure 4.11: Sub soil copper and zinc levels in parts per million (ppm)

The top soil samples (Figure 4.10) had higher concentrations of copper and zinc compared to the sub soil samples (Figure 4.11). The micronutrient levels measured in me% were available in the following order calcium > magnesium > sodium > manganese (Figures 4.12 and 4.13).

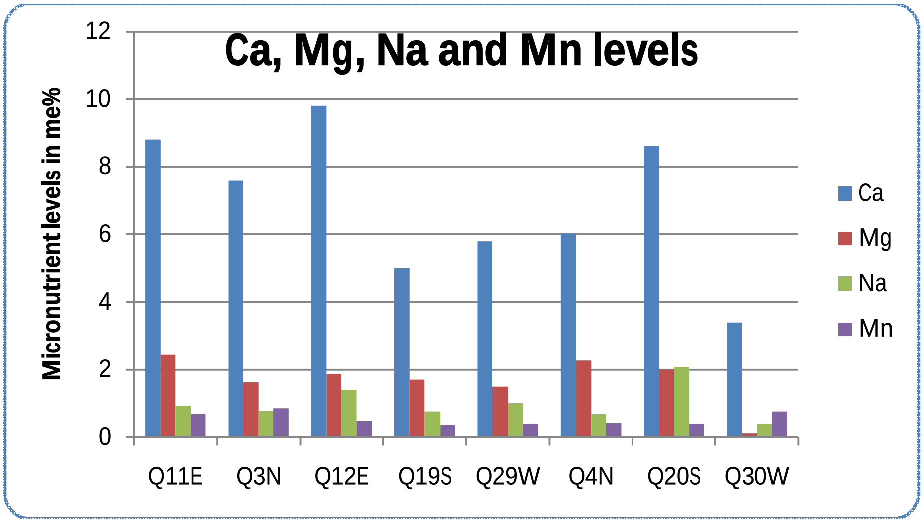


Figure 4.12: Top soil Ca, Mg, Na and Mn levels in me% in Manguo wetland

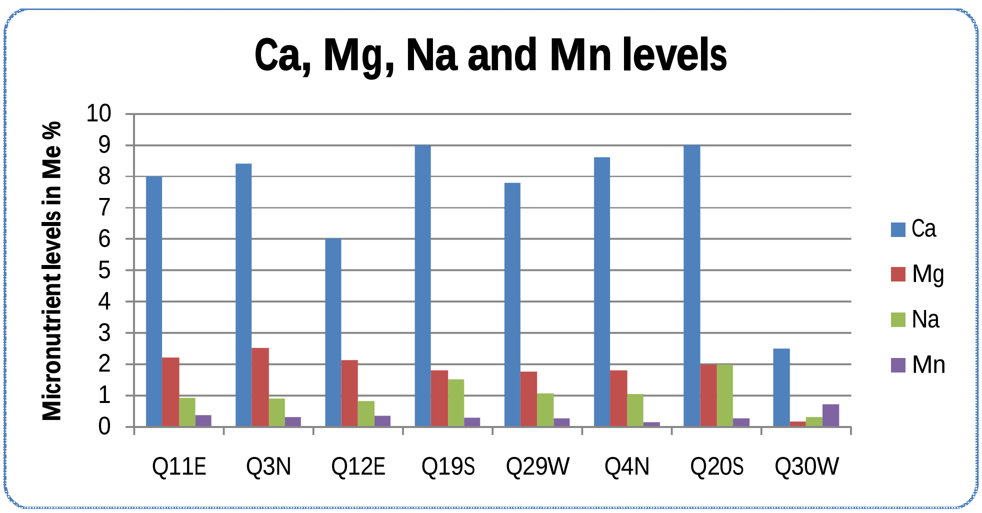


Figure 4.13: Sub soil Ca, Mg, Mn and Na levels in me% in Manguo wetland

Soil texture and moisture.

The soil moisture (Figure 4.15) and texture (Figure 4.14) were analysed using the hydrometer method and the results tabulated (Appendix 10c). It was determined that the Manguo wetland soils are predominantly clay with only 2 of the 16 samples showing a mixture i.e. quadrat 4 top soil showed a silt clay loam consistency while quadrat 12 top soil showed a clay loam consistency.

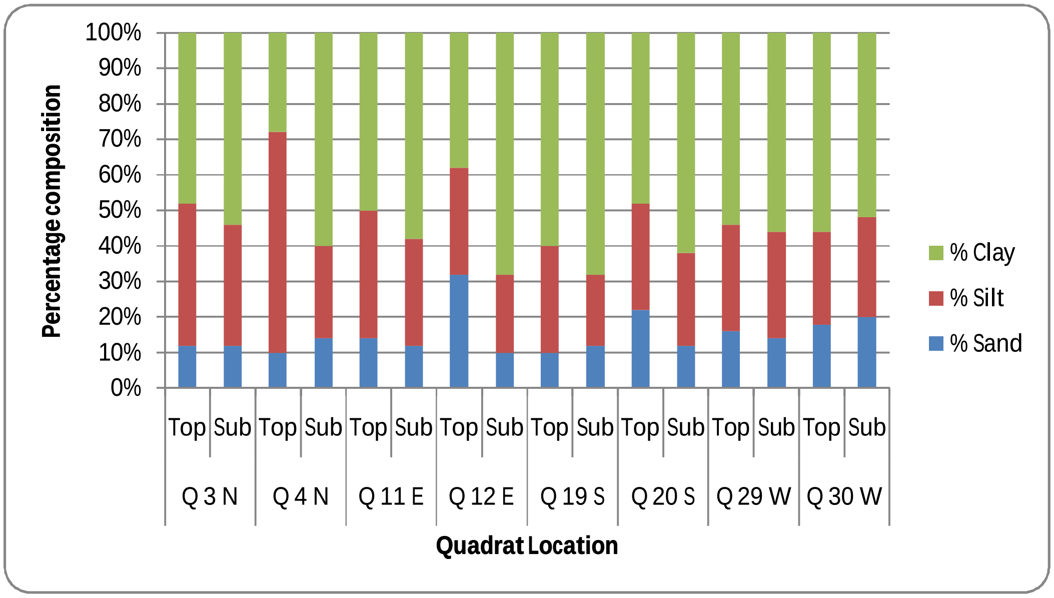


Figure 4.14: Manguo wetland soil texture components

Nearly all the soils sampled irrespective of sampling site had soil texture that was predominantly clay, then silt and loam.

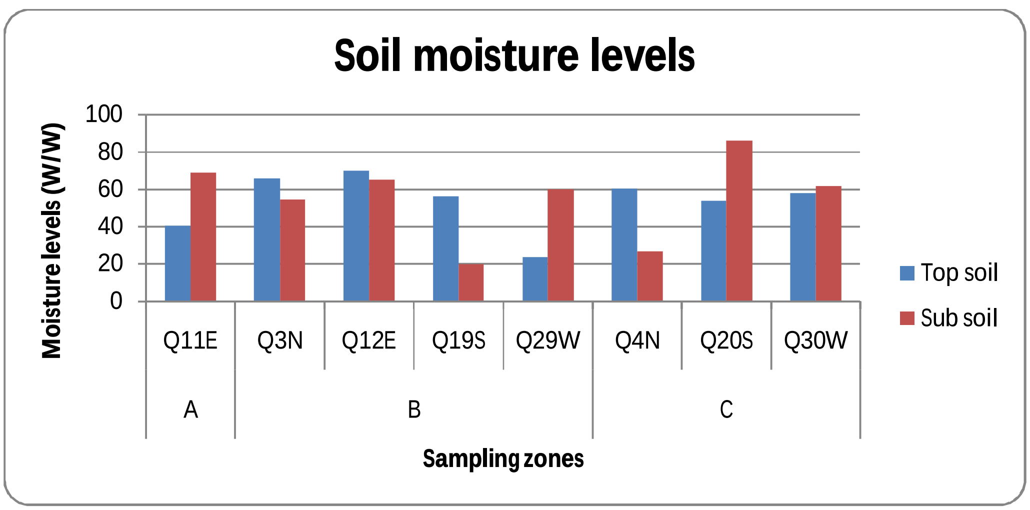


Figure 4.15: Soil moisture levels (W/W) at Manguo wetland

The soil moisture values (Figure 4.15) ranged between 20 - 85 % (W/W) the soil moisture content was dependent on the soil texture components. The high clay levels hold water for long and thus are responsible for water logging. The south and east samples had the highest soil moisture levels as they are situated in the flooded region of the wetland as well as highest clay levels.

4.4 Water physical and chemical characteristics

The water was found to have a pH of 6.09 in the permanent pool and 5.89 in temporary pool (average of 5.99). The water had an average temperature of 21.47˚c. There was no significant difference in the water characteristics of the two pools. This was because it was the same water that overflowed its natural basin when flooding occurred.

The Manguo water had very high chloride levels and relatively high sulphate levels, however the potassium levels were very low at 0.2 me% (Figure 4.18). The wetland was classified as a fresh water wetland, its conductivity levels both in the soil and water fell below 0.5 and carbonates were not detected in the water. (Appendix 11)

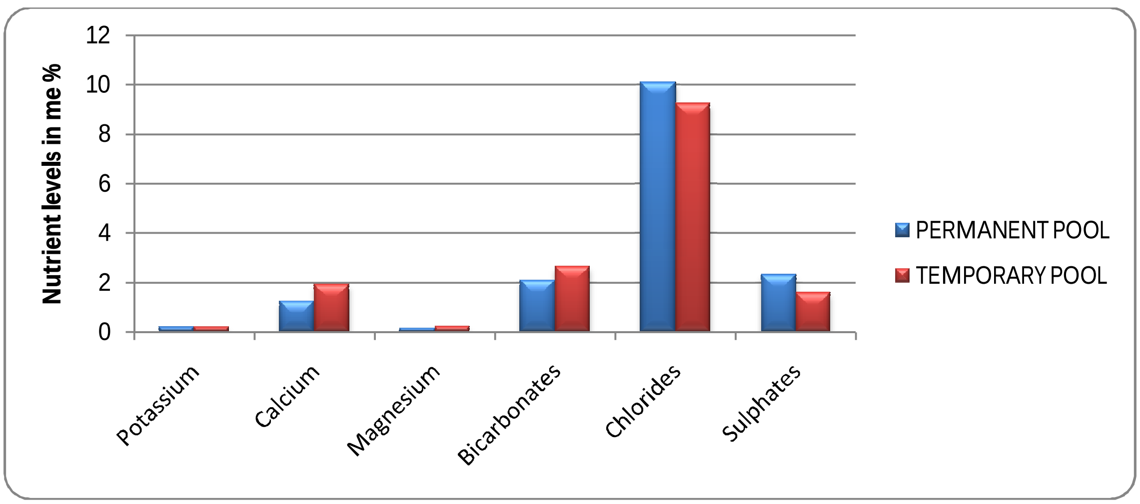


Figure 4.16: Manguo wetland water nutrient levels in me%

The nutrient levels in the two pools were fairly similar apart from the chloride and sulphate levels.

4.5 Palynological assessment

Eighteen pollen types were identified to family level and 31 identified to genus level. A graph showing change of vegetation species overtime was drawn using the Tilia program from which inferences about climatic changes and human impacts were made.

4.5.1 Pollen identified from Manguo core

A total of 48 pollen types from woody, herbaceous and grass vegetation were identified from the Manguo wetland core (Table 4.3). The highest number of pollen identified belonged to herbaceous vegetation with 32 pollen types identified to family and genus level. Pollen from fourteen tree genera were identified to family level and two aquatic families were identified together with spores and spirogyra.

The tree genera identified were from nine orders and twelve families. The order Pinales had the highest representation with three genera (i.e. J*uniperus*, *Pinus* and *Podocarpus).* The herbaceous vegetation pollen types identified were from thirteen orders and eighteen families with order Lamiales having 8 genera from three families. The aquatic plants were from two orders (Poales and Nymphaeales) and two families (Cyperaceae and Nymphaeaceae) thus the least represented.

TABLE 4.3: Pollen types identified at Manguo wetland

Life form	Order	Family	Pollen identified	Authority
Trees	Fabales	Fabaceae	*Acacia*	Mill.
	-	-	*Apodytes*	C.A Sim
	Brassicales	Capparaceae	*Cadaba*	Forssk.
			Capparidaceae	Juss.
	-	Boraginaceae	*Cordia*	L.
	Malphigiales	Euphorbiaceae	*Croton*	
	Malvales	Malvaceae	*Dombeya*	Cav.
	Asparagales	Asparagaceae	*Dracaena*	Vand. Ex L.
	Myrtales	Myrtaceae	*Eucalyptus*	L. Her
	Rosales	Moraceae	*Ficus*	Gaudich ex. L
	Lamiales	Oleaceae	*Olea*	L.
	Pinales	Cupressaceae	*Juniperus*	
		Pinaceae	*Pinus*	
		Podocarpaceae	*Podocarpus*	Persoon
Herbaceous vegetation	Asparagales	Asparagaceae	*Agavaceae*	L.
	Apiales	Apiaceae	*Umbelliferae*	Lindl.
	Asterales	Asteraceae	*Stoebe*	L.
			Artemisia	L. 1753
			Asteraceae	Bercht. & Presl
	-	Boraginaceae	*Boraginaceae*	Juss
	Brassicales	Brassicaceae	*Brassicaceae*	
	Caryophyllales	Amaranthaceae	*Chenopodiaceae*	L.
		Polygonaceae	*Polygonum*	
			Portulacaceae	L.1753
		Portulacaceae	*Rumex*	Juss.
	Fabales	Fabaceae	*Indigofera*	L.
			Senna	Mill.
	Lamiales	Acanthaceae	*Acanthaceae*	L.
			Hypoestes	Sol. Ex R.Br
			Justicia	L.
		Lamiaceae	*Labiatae*	Lindley
			Leucas	
			Ocimum	L.
		Plantaginaceae	*Stemodia*	
	Liliales	Liliaceae	*Liliaceae*	-
	Malvales	Malvaceae	*Hibiscus*	L.
			Malvaceae	Juss.
	Malphigiales	Phyllanthaceae	*Phyllanthus*	L
	Myrtales	Onagraceae	*Ludwigia*	
	Zingiberales	Musaceae	*Musa*	
	Poales	Poaceae	*Poaceae*	L.
Aquatics	Poales	Cyperaceae	*Cyperaceae*	Juss
	Nymphaeales	Nymphaeaceae	*Nymphaeaceae*	L.

4.5.2 Core profile

A vertical cross section of the core was analysed to observe the changes in soil colour and structure (Figure 4.17). The first 7cm of the profile was a water hiatus due to the flooding, the soil profile colour alternated between different shades of brown and grey. Red and brown strips in the layers developed under waterlogged and dry conditions hence they are oxidized iron compounds or rust. The darker colours allow the soil to warm up faster for plant growth. It was rich in organic matter which reduced with increase in depth. The soil changed from dark brown loamy soils to grey coloured soils at the bottom rich in silica.

DEPTH (cm)		CHARACTERISTICS
0 -7		Water hiatus
7 – 9		Dark humus with fibrous roots
9 – 33		Dark brown sticky/clumpy clay soil with fibrous roots and peat.
33 – 57		Compact all grey clay soil.
57 – 81		Dark brown clay soils with brown streaks, humus and fibrous roots. Grey laminations at 60cm.
81 – 105		Very dark clay soils.
105 – 129		Gray clay at the top then orange from mixture of humus and murram.
129 – 153		Murram humus mixture at the top then dark grey clay.
153 – 177		Very dark compacted clay.
177 – 201		Dark grey clay changing to sandy soil with silicaceous matter.
201 – 225		Sandy silicaceous matter.

Figure 4.17: Soil profile

4.5.3 Pollen distribution over time

Three Tilia graphs were generated: one was showing the complete vegetation structure (Appendix 4), one showing the trees (Figure 4.18) and one showing the herbaceous vegetation (Appendix 5). Some taxa with value as indicators of past vegetation were identified and described (Appendix 9).

Each Tilia graphs was divided into five main zones, Zone mang I – V along the soil core as illustrated in Figure 4.18. The zones were created by the CONISS programme which searched the dataset for the two most similar, stratigraphically-adjacent, samples, and combined them. The combination was then treated as a single sample, and the search repeated thus giving four zones. The lithology was described along the core profile.

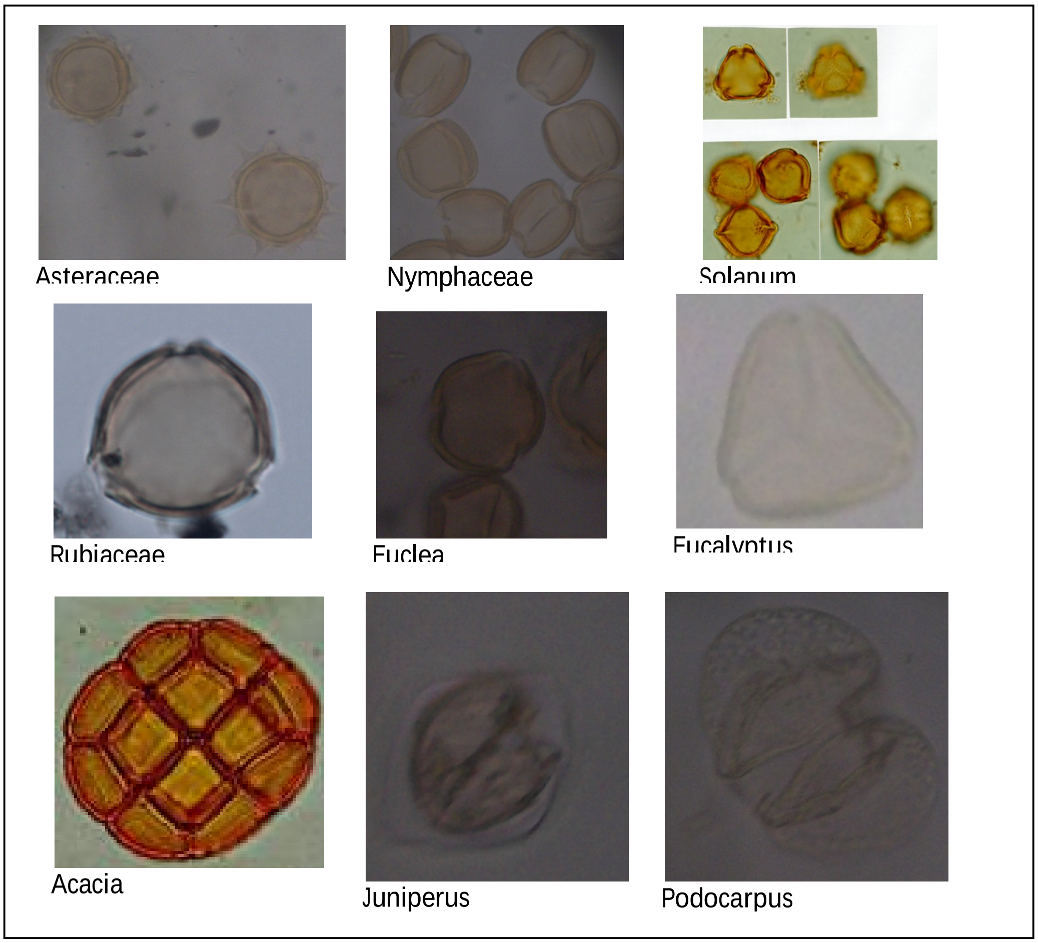


Plate 4.1: Pollen identified from Manguo Wetland core.

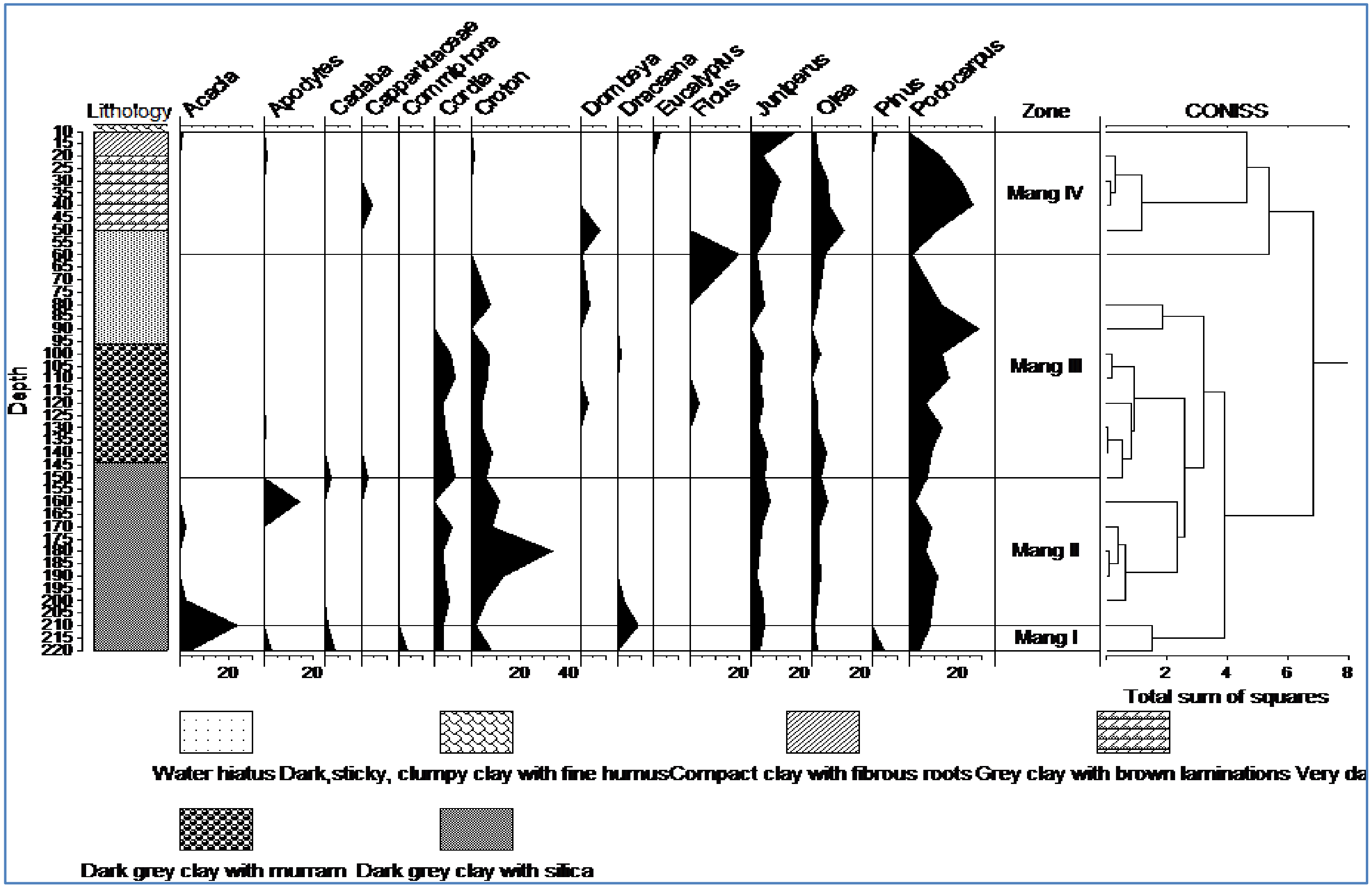


Figure 4.18: Tree Tilia diagram

Tree species identified from pollen in core and their abundance over time along a lithology description.

Zone Mang I (220 -210cm)

This zone was from 220cm -210 cm; it was represented by 11 trees and shrub species out of 15 that were observed in the whole column. The most dominant species here were the *Acacia, Croton, Dracaena, Juniperus* and *Podocarpus*.

Capparidaceae, *Dombeya*, *Eucalyptus* and *Ficus* were absent from this zone. *Acacia* increased from 5% to 25% to the zone boundary. *Apodytes, Cadaba* and *Commiphora* and *Pinus* were at 5% but substantially decreased towards the boundary. *Croton* also decreased from 10% to around 3% at the boundary. However *Cordia* remained present through the whole zone at 5% together with *Olea* which was present throughout the zone at around 3%. *Dracaena*, *Juniperus* and *Podocarpus* all increased towards the boundary with *Dracaena* from 0 – 10%, *Juniperus* from 5 – 10% and *Podocarpus* from 5 – 15%.

17 herbaceous species were represented out of the total 32 species present in the whole column. Of the 17 the most dominant families were the Acanthaceae, Agavaceae, Asteraceae, Poaceae, *Zea mays* and *Phyllanthus.*

The only genera present were the Cyperaceae which decreased from 20% to 5% at the boundary. Nymphaceae, spores and spirogyra were absent from this zone.

Zone Mang II (210 -150cm)

It was represented by eight trees and shrub genera out of 15, the most dominant were *Acacia, Apodytes, Croton, Dracaena, Juniperus, Olea* and *Podocarpus.*

Acacia drastically reduced from the 20% at 210cm to less than 5% at 192 cm then completely disappeared until 177cm-165 cm where it was at 5% before disappearing again. *Apodytes* started appearing at 175cm where it steadily increased until 18% at 160cm then started reducing until it disappeared at the 150cm boundary. Capparidaceae and *Cadaba* appeared at 160cm increasing to 5% at the boundary. *Cordia* fluctuated within the zone from 5% to 10%; its lowest presence was at 160cm where it was less than 2% but it steadily increased to 10% at the boundary.

Croton steadily increased from less than 5% at 210cm to 35% at 180cm then reduced to 7% at 175cm before rising to 15% at 160cm then steadily decreased to 7% again at the 150cm boundary. *Croton* had the highest presence in this zone at 35%.

Dracaena reduced from the 10% at the 210cm to less than 2% at 192cm before completely disappearing. *Juniperus* and *Olea* fluctuated within the zone at percentages between 2 -8%, they both attained there highest percentage at 160cm which was 8%. *Podocarpus* steadily rose from 10% to 15% at 192 cm before reducing to 5% at 180cm; it then increased again to 12% at 170cm before reducing to its lowest level of 2% at 160cm then steadily rose again to 10% towards the 150cm boundary.

Commiphora, Dombeya, Eucalyptus, Ficus and *Pinus* were completely absent throughout the whole zone. There were 15 species represented out of the 32, the most dominant were the Acanthaceae, Agavaceae, *Artemisia, Asteraceae,* Poaceae, Euphorbiaceae, Malvaceae, Labiatae, Portulaceae, *Zea mays* and *Phyllanthus.*

The aquatic genera present were the Cyperaceae and Nymphaceae, the Cyperaceae fluctuated between less than 5% and 30%, while the Nymphaceae were all less than 5% at 210 cm – 200 cm. Spores and spirogyra were absent from this zone.

Zone Mang III (150 -60cm)

It represented seven genera of trees and shrubs species out of the 15, the most dominant were *Cordia, Croton, Ficus, Dombeya, Juniperus, Olea* and *Podocarpus.*

Cadaba and Capparidaceae were present at 5% but reduced completely at 145 cm. *Cordia* steadily reduced from 20% to less than 5% at 120cm before increasing to 20% then reducing and completely disappearing at 92cm. *Croton* fluctuated between 5% and 15% before completely disappearing at 92cm, it then steadily increased.

Dombeya was absent until 130 cm where it increased and peaked at 125 cm with 5% then gradually decreased and disappeared at 112 cm. It then appeared again at 91 cm gradually increasing until it peaked at 80 cm with 5% and decreased again towards the boundary. *Ficus* was also absent and appeared at 130 cm gradually increasing and peaked at 125 cm with 3% then decreased and disappeared at 111cm. It then appeared again at 80cm where it gradually increased towards the boundary until it peaked at 15%.

Dracaena appeared at 115 cm to 95 cm but at <1%. *Juniperus* fluctuated throughout the zone between <1% and 10%. It was highest at 145 cm, 100 cm and 85 cm and lowest at 91 cm where it was less than 1%. *Olea* fluctuated between <1 % and 8%, at 115 cm and 95 cm had the lowest levels at <1% and the highest peak at 141 cm with 8%.

Podocarpus was the most dominant species in this zone fluctuating between 5 % and 30 %. It was lowest at 121 cm with 5 % and highest at 88 cm with 130 cm. *Acacia, Apodytes, Commiphora, Eucalyptus* and *Pinus* were completely absent.

11 of the herbaceous species were well represented here with Acanthaceae, Agavaceae, *Artemisia,* Asteraceae, Labiatae, Malvaceae, *Stoebe, Zea mays,* Poaceae, Cyperaceae as the main pollen grains in this zone.

Zea mays fluctuated between 5% - 10% at 150 cm to around 103 cm when it started reducing and disappeared at 90 cm however it started increasing almost immediately and stabilized at 70 cm at 10 % where it remained till the 60 cm boundary.

Cyperaceae was highly present throughout the zone fluctuating between 10% and 20%; however at the 60 cm boundary it drastically reduced to less than 5% while Nymphaceae was present between 111 cm and 92 cm at levels below 5%. Spores and spirogyra were absent in this zone. Boraginaceae, Brassicaeae, Cruciferae, Cucurbitaceae, *Hypoestes, Rumex, Senna* and Umbelliferae were completely absent from this zone.

Zone Mang IV (60 – 10 cm)

11 of the 15 trees and shrubs were present, however only six were present at significant levels of 5% and above. They included; Capparidaceae, *Dombeya, Ficus, Juniperus, Olea* and *Podocarpus.*

Acacia was only present in this zone at 20 cm -10 cm at <2%. *Apodytes* was present between 28 cm – 12 cm also at levels < 2%. *Croton* was only present at 27 cm and 16 cm at < 1%. *Eucalyptus* appeared at 25 cm and slowly increased towards the 10 cm but only reached a peak of 3%. *Ficus* was at 15% at the 60 cm boundary however it steeply decreased and eventually disappeared at 50 cm. Capparidaceae appeared at 50 cm and it gradually increased to 5% at 40 cm then started to decrease again until it disappeared at 32 cm.

Dombeya started increasing from 60 cm to 50 cm where it peaked at 7 % before it started reducing again and completely disappearing at 40 cm. *Juniperus* started off at <5% at the 60 cm boundary and gradually increased to 10 % at 52 cm before slightly reducing to 7%

between 48 cm - 40 cm then starts increasing again to 15 % at 30 cm then a sharp decrease until it reached 5% at 20 cm and then started increasing again to 20 % at the 10 cm boundary. *Olea* started off at 5% at the 60 cm boundary and peaked at 50 cm where it reached 15% before it started reducing gradually. At 20 cm it was 5% and continued decreasing till <1% at the 10 cm boundary. *Podocarpus* started at <5% at the 60 cm boundary, increased until it peaked at 42 cm at 25%. Here it started reducing again until it disappeared at the 10 cm boundary. *Cadaba, Commiphora, Cordia* and *Dracaena* were absent.

Ten out of the 32 herbaceous genera/species were present at significant levels of 5% and above. Acanthaceae, Asteraceae, *Zea mays* and Poaceae were the most dominant herbaceous species. Cyperaceae had the highest presence in this zone than it did in all the other zones. It steadily increased from <1% at 60 cm until it peaked at 30 cm at 60%, it then started reducing sharply till 20% at 25 cm. Between 25 cm – 10 cm it was still reducing gradually to around 15% and Nymphaceae was present at levels <1% between 30 cm and 15 cm.

Spores and spirogyra were present in this zone. Spores appeared at 25 cm where they increased to 10%, spirogyra appeared at 35 cm and gradually increased to 20% at 20 cm before they started decreasing towards the boundary to 15%.

The final zone which did not appear in the zone profile was the top 7cm which was the water hiatus, the wetland was constantly flooded at the edges which were dominated by sedges.

4.6 Land use activities identified at Manguo wetland

Manguo wetland basin has got various uses as was observed during the data collection period. They included: Dumping of solid waste (Plate 4.2), burning of garbage leading to huge blackened patches on the landscape, livestock grazing of mainly donkeys (Plate 4.3) thus a lot of trampling and water disturbance leading to constant water turbidity, harvesting of the sedges in large quantities, water abstraction through a borehole drilled right at the edge of the wetland for a car washing business. These activities were observed between August 2011 and March 2012 and they were carried out during most days.

Plate 4.2: Solid waste in Manguo wetland

Plate 4.3: Donkeys grazing in Manguo wetland

CHAPTER FIVE

DISCUSSION

5.1 Manguo wetland vegetation structure

In their natural environment plant survival, growth and distribution depend on the soils physical and chemical characteristics. To survive changes, plants must have the ability to adapt. The purpose of this study was to gain better understanding of the structure of Manguo wetland plant community in response to local soil and water conditions and its changes over time.

Wetland species undergo changes in relative abundance throughout the year, particularly in response to seasons. Seasonality (wet and dry) influences the depth and duration of flooding which has an effect on germination and establishment of wetland plants and completion of the life cycle through to sexual or asexual reproduction (Warwick and Brock, 2003). This is caused by 'phenological' differences among species in the time of year in which they germinate, begin growth, peak in biomass or flowering and die back. There was a comparison between the data collected in the dry and wet period to determine the similarity between the samples.

The species composition of the samples was found to be highly similar between the wet and dry periods; most of the species recorded during the dry period were also present in the wet period implying that the soil moisture conditions in the wetland did not change significantly between the two periods of study.

Analysis to determine change in the abundances found that the species abundance was dependent on the season and this was despite the fact that there was little difference in terms of soil moisture. Furthermore, there were minimal changes in the hydrology and soil characteristics. These conditions ensured that plant species changes noted were in abundance and not composition. There was an increase in the abundance of sedges and decrease in the grass abundance but the species composition was similar.

Species richness (which is the number of species within the habitat) is often used as a measure of species biodiversity. However, it does not differentiate between exotic and indigenous species. The species richness values were quite close due to the fact that very little change was observed during the two sampling periods in terms of numbers species sampled.

The wet period sampling gave a higher species abundance than the dry period sampling although the same number of species were sampled during both sampling periods. The number of individuals (N) changed from 6387 to 4272 and this could be due to the fact that increase in precipitation initially leads to increase in yield and plant species that could not tolerate the flooding disappeared and a few new flood resistant plants had become established.

The effect of seasonality and zonation on species abundance and the level of interaction (seasonality and zonation) if any on the species abundance was assessed; the wet and dry periods were found to have a higher influence on plant abundance than the zones along the soil moisture gradient. Between zones, the highest variance was between zones A and C and this could be because Zone A was a flooded region while C was a dry area. There was no significant interaction between the seasons and the zonation, and this was attributed to fairly similar soil moisture content throughout the wetland because it was all flooded apart from zone C which was dry, thus no much difference between the zones. By the time of sampling the rainfall had not yet resulted in significant flooding that could interact with the zonation and influence the vegetation abundance and distribution.

Global climate change has been shown to influence the distribution and functions of wetlands by altering their hydrological regimes (changing water availability and depth, duration, frequency, and season of flooding) outside their normal range (Galbraith and Huber-Lee, 2005). The hydrological regimes would also influence wetland vegetation community structure and distribution. In Manguo wetland, the species composition and distribution does not vary greatly between the dry and wet period and across the wetland. This conclusion should be further ascertained by establishing a long term monitoring plan that will take into account the continuous climate change and land use patterns. As for the similarity in vegetation structure within the wetland this is because the wetland is very small and thus the environmental variables especially the soil properties would not be expected to vary within the wetland unless in special areas e.g. a burning point or areas where animals were regularly tethered.

5.2 Soil and water characteristics of Manguo wetland and their influence on vegetation distribution

Physical and chemical properties have been widely used as indicators of soil and water quality because of their essential role in soil functioning, ease of measurement, and sensitivity to environmental change. Research has determined that plants require 17 nutrients also called ‘essential elements’ (Marschner, 1995). Each nutrient is required for completion of the plants lifecycle and its function cannot be replaced by another element (Jones, 2001). An adequate and balanced supply of all the nutrients essential for ecological processes and functions is required to maintain ecosystems at optimum state. However this is not always possible due to the dynamic state of nature. One of the main objectives of conservation is to maintain ecosystem health and resilience and can be achieved by determining the optimum ecosystem states and trying to achieve them.

In a wetland, the water and soil nutrients and characteristics are a major focus. The texture and chemical composition of the soils are major factors determining what kind of plants can grow well in a particular location. Plants that grow naturally in a certain type of soil are adapted to its mineral content and texture and are able to absorb water and extract essential nutrients from that soil.

Manguo wetland soil was more acidic than the water, with the water having an average pH of 5.99 while the soil had an average pH of 5.42 which could be caused by the nutrients that are held by the soil. According to a study done in 2001, Kiambu district soil ph ranged between 5 and 6 the same pH range as observed (Makokha *et al*, 2001). The wetland water can be classified as soft because soft water has a ph range of 5.3 – 7.4. Carbonates were not detected and the water had a low concentration of calcium. Water is classified as hard when $CaCo_3$ concentration levels in mg l^{-1} are above 100 and fresh when conductivity levels are below 0.5dS/m (Dekeyser, 2006).

PH value of the water has dropped from the 2007 values indicating that the water has become more acidic, the soil pH values would be classified as strongly acidic to acidic (Sandor, 2007). This could be due to the constant state of water logging, increased use of fertilizers in the farmlands, increased soil erosion, increased leaching or even increased grazing which has led to increased amounts of dung with high nitrogen content. Determining the specific sources of pollutants and their components would be essential in pin pointing what activities have the highest impacts on the wetland.

Manguo wetland soils are predominantly clay which means they hold water for long periods of time and also have a high cation exchange capacity due to the large surface area for adsorption. Clay loamy soils are fine textured with more clay size minerals, high porosity, but small discontinuous pores. The soil usually shows platy structure because it is subject to leaching or compaction. The soil moisture levels were considered to be normal for a wetland with clay soils and ranged between 20-85% W/W. Clay soils are very dense making it difficult for plant roots to establish, they are also capable of holding a huge quantity of water, but water movement is very slow due to high surface tension. Often waterlogged soils have a problem with aeration, because air movement is also very slow. The process of mineralization is restricted in this type of soil. Available water for plant is usually 5ml per 30cm soil. The adsorption of nutrients and the microbial activity are dependent on the total surface area of the soil. The fine textured soil has a larger total surface area than that of the coarse textured soil as decreasing the particle size, increases the surface area thus more nutrients are available to the plants.

Most of the nutrient levels were found to be in higher concentrations in sub soil samples compared to the top soils and this result was attributed to nutrient leaching during flooding of the swamp from the top to bottom soil layers.

Organic carbon and nitrogen levels were higher in the top soil samples compared to the sub soil samples. This could be caused by the higher level of plant material on the top soil that decomposes slowly due to the water logging. The high nitrogen levels could also be as a result of the abundance of dung from the various livestock that grazed in the Manguo wetland. High organic matter content measured as organic carbon has a high surface area thus a high cation exchange capacity and supply of nutrients. Kiambu district soils had a high organic carbon (C) content (3-4%) as determined by a 2001 study reflecting high levels of applied organic matter, most likely coupled with low rates of mineralization. The higher the organic carbon levels the better the soil fertility and the soils at Manguo wetland were classified as having adequate carbon levels ranging between 0.89-8.02%. Soils in Kiambu generally have low N (0.2- 0.3%), indicating that more N needed to be added (Makokha *et al.*, 2001). At Manguo wetland total N% ranged between 0.11-0.8 percent.

Wetlands can remove and store large amounts of N and later release to the ecosystem mostly in organic forms. The wetland could be acting as a nutrient sink thus concentrating nutrients in soils. The nutrients could have been leached down or arrived through soil erosion. High carbon: nitrogen ratios were observed and are a sign of nitrogen mineralization taking place, a common attribute in wetlands which makes them good carbon sequesters.

Phosphorous was readily available due to the optimal soil pH as phosphorous is most available between a pH range of 5.5-6.8. Most plants respond to P additions when soil solution levels are less than 0.1 to 0.2 ppm. Manguo wetland soils have phosphorous levels ranging between 22-63 ppm which is more than adequate. The levels observed are considered high with a high to excessive sufficiency range (Stevens *et al.*, 1999). The sufficiency range estimates the amount of yield response for each soil test range. Potassium (K^+) is largely present in the soil but only a small percentage is available for plant uptake (1-10%), it is slowly made available through the cation exchange process.

Micronutrients are more available in acidic than alkaline soils which is an advantage for Manguo wetland. For example, copper, iron, manganese and zinc are all more available at low pH levels than at high pH levels because metals are bound very tightly to the soil or exist in solid minerals at high pH. Conversely, the ‘base’ cations (Na^+, K^+, Ca^{+2}, Mg^{+2}) are bound more weakly to the soil, so can leach out of the surface soil, especially at low pH. Minerals with a positive charge, such as potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}), adhere by electrical attraction to the negatively charged surfaces of clay particles. Clay in soil prevents the leaching of mineral nutrients during heavy rain or irrigation because of the large surface area for binding minerals (Brady, 2002).

Copper is more strongly bound to the soil particles than any other micro nutrient as most of the Cu^{2+} is adsorbed with clay and organic matter. The high copper levels could be because Manguo soil is dominantly clay thus a lot of copper ions are adsorbed to the clay. It was found to be one of the factors influencing Manguo wetland vegetation distribution.

Iron however is highly abundant with total solubility ranging from 0.7%-55%. Manganese (Mn) deficiencies occur most often on high organic matter soils; however soil moisture also affects Mn availability. Excess moisture in organic soils favors Mn availability because reducing conditions convert Mn^{4+} to Mn^{2+}, which is available to plants thus it is readily available in swamps as indicated by the adequate amounts of Manguo wetland.

Minerals with negative charges, such as nitrate (NO^{3-}), phosphate ($H_2PO_4^-$), and sulfate SO_4^2), are usually not bound tightly to soil particles and thus tend to leach away more quickly. This could be the reason why the sulphate ions are in high levels in the Manguo water. Positively charged mineral ions are made available to the plant when hydrogen ions in the soil displace the mineral ions from the clay particles. This cation exchange is stimulated by the roots which secrete H^+ and compounds that form acids in the soil solution.
Cation-exchange capacity (CEC) which is the measurement of the soil's ability to hold positively charged ions and nutrients is critical and understanding principles of soil cation exchange is important to understanding the mobility or immobility of fertilizer or other ionized chemicals in the soil. The CEC of a soil increases with increasing clay or organic matter content and so does the reactivity and buffering capacity of a soil. Soils with a higher CEC typically are more fertile than those with a lower CEC, as the former tend to retain plant nutrients that the latter would lose through the leaching process.

Soil salinity refers to the concentration of soluble inorganic salts in the soil and is measured as electrical conductivity. It is important as it reflects the extent to which soils are suitable for growing crops; values of 0-2mmhos are suitable for most vegetation (Richards, 1954). Thus Manguo wetland soils are considered relatively fertile as the soil nutrients are available in adequate levels and the pH, salinity and CEC values are of optimal values. The wetland should therefore be able to host a wide variety of biodiversity.

Sodium adsorption ratio (SAR) is a measure of the suitability of water for use in agricultural irrigation, as determined by the concentrations of solids dissolved in the water. It is also a measure of the sodicity of soil, as determined from analysis of water extracted from the soil. Increasing concentrations of sodium and chloride ions in groundwater and surface water can adversely affect environmentally-sensitive areas such as wetlands. High levels of chloride ions is primarily a sign of leaching but today it is also a sign of presence of industrial and municipal waste. Sodium and chloride contamination within a wetland's watershed and recharge areas can destroy rare and endangered plant species.

Sulphate ions are present in all surface water and their content is limited by the presence of calcium with which they form a slightly soluble calcium sulphate. Enrichment by sulphide is mainly through oxidation of sulphide from the earth's crust and the atmosphere, decomposition and also human economic activities. The knowledge on the chemical composition of natural waters is essential for water classification, definition of fitness for different uses and to register when pollution occurs.

5.3 Relationship between soil characteristics and plant distribution.

Manguo wetland vegetation changes with soil moisture but not significantly. Plants that occur near the borders are rare plants either because of their abundance or because of the occurrence on sites with extreme environmental conditions. *Plantago palmata* and *Sphaeranthus napiera* occurred near the border however they had average abundance. *Sphaeranthus napiera* is endemic in Central Kenya fresh water wetlands (Agnew, 2004). Only a few *Hagenia abyssinica* plants were observed. Quadrat thirty also occurred at the ecotones and the soil sample from this site had very low nutrient levels.

The unconstrained ordination gives a basic overview of the compositional gradients in the data. The first axis explained a variance of 43% and the second axis explained 10% of the variance. A constrained ordination analysis (Canonical correspondence analysis) was then carried out, the first axis explained 42.7% and the second axis explained 22.7% of the variability. The first axis was positively correlated to potassium, copper, manganese, acidity and moisture while negatively correlated to Ph and magnesium. The second axis is positively correlated to moisture, acidity, conductivity and sodium but negatively correlated to magnesium.

The first gradient could be the ph while the second should the moisture gradient which is strongly related to the acidity. However the results of the CCA analysis showed that Copper, Potassium and pH were the most important factors in influencing the vegetation distribution.

5.4 Manguo wetland soil profile

A mottled color pattern is seen in soils that are wet for part of the year, the alternating patterns of red and gray colors indicate that some of the iron has been reduced or depleted (exposing the gray colors) and has been concentrated in the red patches. Iron oxides and organic matter are the two primary coloring agents within most soils. Organic matter makes the soil brown or black.

The majority of the soil, though, was made up of alumino-silicate minerals, which are white to gray in color. Gray colors arose because iron oxides had been reduced, become soluble, and translocated down the soil column, usually because of saturated and anaerobic conditions. The top levels of the soil were rich in organic matter hence the dark brown colour, it changed downward as the amount of organic matter reduced. It was also streaked with bands or red/brown indicating levels rich in iron.

5.5 Historical vegetation changes

The vegetation distribution pattern in East Africa closely mimics the rainfall and topographic conditions as well as the length of the dry season (Kiage 2006). Tertiary plant fossil localities currently are under wide spread investigation, providing many different datasets for the reconstruction of paleoclimatic conditions and paleo-ecosystems (Meller *et al.,* 1999). Depending on the paleobotanical discipline, the datasets are quite variable, and the interpreted paleo-vegetation types tend to be based on preserved organs of woody plants such as leaves, diaspores, or palynomorphs.

A lot of palynological studies obtain samples from wetlands (Vincens *et al.,* 1998, DuPont *et al.,* 2011, Lebamba *et. al.,* 2012) for reconstruction of vegetation and climate. Plants differ greatly in the amount of pollen they produce, settling velocities and dispersal abilities. The pollen analysis revealed that there were taxa present in the wetland but not represented in the pollen which is as a result of changes in vegetation structure overtime and the amount of pollen produced by some plants. Some of the taxa were represented in the pollen samples but not in the wetland vegetation sampled. This is because the pollen is transported from far and some of the vegetation types have been lost over time.

Pollen can either be over represented or under represented. Under representation of taxa occurs when pollen count is very low indicating that the plant does not produce a lot of pollen and the little that is produced is deposited close to the site, this occurs when pollen percentage is less than 5%. For example, *Canthium*, *Acacia* and *Croton* produce heavy pollen of low dispersal ability and could therefore be underrepresented in a sample. There presence in the lower depths of the core is an indication that they were present in the vicinity of the wetland. In contrast some plants such as *Podocarpus* produces huge amounts of pollen with high dispersal ability, thus they tend to be over represented. Its pollen presence in the core is and indicator of its presence in the Manguo catchment area.

Forest species identified from pollen included: *Croton macrostachyus* which tends to be abundant in the montane rainforest (Livingstone, 1967). *Olea*, a dry montane rainforest tree with three common species that occur in Kenya i.e. (*Olea hochstetteri, Olea capensis, Olea* *europaea* sub.sp. *africana).* It is common in many pollen diagrams from East Africa (Mworia-Maitima, 1991; Lamb *et al.,* 2003; Ryner *et al.,* 2006; Vincens *et al.*, 2006). This is because many members of the Oleaceae family are widely distributed in the dry forests. *Podocarpus* has high relative export ability (Hamilton and Perrot, 1980) and Coetzee (1967) suggests that when *Podocarpus* pollen is lower than 10% it reflects absence of the species but when it is >20% it indicates close proximity. *Juniperus procera* covers a distribution area largely coinciding with that of *Olea europaea ssp cuspidata*; it is also associated with *Podocarpus*. It is an important component of a forest that is transitional between dry, single-dominant afro-montane forest and semi-evergreen bush land and thicket. *Juniperus procera* will not regenerate in mature forests but is replaced by Podocarpus forest and similar forest types because it is highly susceptible to fire. It occurs at an altitude: 1100-3500 m with a mean annual rainfall of 400-1200 mm and prefers well-drained soils no heavier than sandy clay and can also be found scattered on rocky sites; limestone, gneiss and granite of the basement complex and basalt.

The presence of forest species in Manguo wetland pollen core is an indicator of the change in vegetation structure overtime from a predominantly wooded ecosystem (forest) to open grassland. The cause of change is predominantly anthropogenic, the deforestation of the Kikuyu escarpment escalated as farming communities moved into the region opening up the land for settlement and farming.

Woody species are also used in the inference of climate depending on the abundance of the indicator species. For example *Acacia* and *Juniperus* are dry upland forest species therefore an indicator of a dry climate while *Olea* and *Podocarpus* are moist upland forest species thus an indicator of a moist climate. Thus the presence and abundances in several levels of the core profile are an indication of the changes in climate overtime. High presence of upper montane and montane forest taxa indicates the presence of a semi -closed canopy vegetation within the locality, suggesting relatively cool, moist conditions. A high percentage of *Podocarpus*, which is a well-dispersed pollen type (Hamilton, 1972) supports this conclusion.

Herbaceous vegetation consisted mainly of ephemeral species that come up depending on the environmental conditions. Asteraceae are human disturbance indicators and their high and constant presence throughout the core is an indication that the wetland has been a constantly disturbed ecosystem. Amaranthaceae/Chenopodiaceae are another indicator of human presence as most of the species are cultivated for food thus they tend to occur near settlement areas.

From the pollen data, the vegetation composition contains a consistently high presence of montane and sub montane species. *Juniperus, Olea, Croton* and *Podocarpus* are the most dominant tree species within the profile. *Acacia, Croton and Podocarpus* have high abundances of more than 20% thus they can be considered as indicators of past local vegetation. A presence of less than 20% of woody/forest species is an indicator of the pollen having being transported from farther away (allocthonous). However, with herbaceous vegetation all pollen types identified are of vegetation within the locality.

The retrieved core was relatively young; this was inferred from the presence of disturbance indicators such as Asteraceae with high abundance values which suggest increased human activity. Presence of cereals (maize) at the bottom pollen samples which was introduced for cultivation around 200 years ago. Human activities in this region are recorded to have begun in the 1800's.

The change in landscape from a high density montane forest to a highly cultivated area has been driven mainly by man. This is evidenced by the presence of *Hagenia abyssinica* which is a fire tolerant species (Lange *et al.*, 1997); typically forming mono-specific stands between the upper montane forests and scrubland (White, 1983). It may act as a pioneer species, replacing moister forest types following burning (Greenway, 1973). However, the pollen count was low and therefore its presence could just be a random occurrence or pollen was inadvertently driven to the wetland.

The introduction of exotics such as *Pinus, Eucalyptus* and *Cupressus* in East Africa and other parts of the continent and their high pollen percentages in the core suggests that their introduction in the twentieth century (1930's) would serve well as indicators in the recent stratigraphy (Burney, 1988).

Cyperaceae and Poaceae are known to occur in all vegetated wetland sites in East Africa and therefore cannot be used as indicators of vegetation zones as they are common in all zones. Poaceae (grasses) may indicate an area of a relatively disturbed semi-arid environment or cultivation under moist climate. The high presence of Poaceae suggests an open and drier environment which is further supported by the presence of montane species which indicate unimpeded long distance transportation from the highland regions. Low presence of aquatic taxa is another indicator of drier climate. Thus soil core levels where Cyperaceae and Nymphaceae were low could represent a dry period (Ashley *et. al*, 2004).

Chenopodiaceae which were also present in high numbers are annual herbs, sub-shrubs, or shrubs, rarely perennial herbs or small trees. Many species of Chenopodiaceae are adapted to and are major components of arid or ruderal environments. They are often intimately involved with the daily life of people together with the genus *Phyllanthus* (Euphorbiaceae), which has between 550 to 750 species as medicinal herbs. Several of these plants produce useful secondary metabolites which have been extracted from whole plants for medicinal use (Bajaj, 1996).

Spores were present but in low numbers and only at the top samples, the low capacity of moss and fern spores being transported by wind is well known (Traverse, 1988). The relatively low frequency of fern spores in surface samples was probably caused by their allocthonous origin for example during water influxes.

The wetland has been through changes in vegetation structure and type. The contemporary vegetation type and modern pollen shows a high abundance of herbaceous vegetation indicating disturbance and settlement with little diversity in woody species. This implies that the landscape vegetation structure has dramatically changed with the main driver in the catchment area been human activities from around 200 years ago in the area. Pollen is an invaluable tool as it reflected the vegetation changes overtime.

5.6 Impacts of human activities on wetlands

Land use practices such as agriculture exert a major influence on plant productivity, soil and plant nutrient content, and within-stand nutrient cycling in wetlands (Gathumbi *et al*., 2005). Manguo wetland is located in an agricultural zone and thus the catchment area is mainly cropped, in the immediate vicinity of the wetland there is mostly small scale farming of maize, beans, kales coupled with agro forestry mainly of eucalyptus. The land slopes down into the wetland and thus there is a lot of soil erosion into the wetland. Vegetative wetlands can be effective at immobilizing, storing and transforming chemical inputs from uplands (Schultz *et al*., 1994).

Expanding industries and urban centers in the Manguo watershed discharge their waste water into the wetland. The polluted waters are unhealthy for human and livestock use, destroy aquatic life, and restrict recreational opportunities (Ramsar Convention, 2001).

5.6.1 Impacts on vegetation

Changes to vegetative and reproductive output have the potential to alter species population dynamics and potentially change the vegetation community. The changes could be brought about by cultivation, deforestation but mainly agriculture through grazing for example when trampling or over consumption exceeds species recruitment. Trampling by livestock is known to affect species composition with some species being better adapted to compact soils or requiring bare patches created to establish (Grevilliot and Muller, 2002).

Removal and trampling of vegetation by grazing animals and humans also affects water birds and invertebrates. Birds are affected by degradation of the habitat such as trampling of nests. However, grazing of livestock can also be beneficial to shore birds that require large areas of open water by reducing the density of the vegetation. It has also been found that light grazing, by livestock in wetlands was beneficial to water fowl and waders (Buxton, 1991) however at Manguo grazing occurred at a high intensity.

The impact on invertebrates is mostly negative because of destruction of vegetation necessary for mating perches, emergence and oviposition sites. For example, one of New Zealand's' native dragon flies *Uropetala oarovei* is especially sensitive to cattle grazing (Winstanely and Rowe, 1980).

5.6.2 Impacts on soil

Livestock grazing in wetlands alters the soil structure due to trampling. It increases soil compaction and reduces water infiltration. Hence nutrients are not leached to the lower levels and could be the reason why if an area is continuously heavily cropped or overgrazed the nutrients consistently reduce until the soil eventually loses its fertility.

During the dry season, soils that are not protected are likely to be eroded if trampling occurs. The soils are fractured and pulverized into small aggregates through surface run off. This could be caused by overgrazing or even use of heavy machinery for example, vehicles. High inputs of fertilizers and dung are also responsible for changes in soil chemistry such as lowering of ph, increasing some nutrients to potentially toxic levels.

5.6.3 Land use impacts on the water

Human utilization of wetlands is almost always negative unless conscious efforts are maintained when using the wetlands. Studies reveal that land use in wetland basins result in reduction of water quality through increased turbidity, reduction in water volume due to evaporation, soil erosion and siltation, increase in nutrients thus reducing suitability of the wetland water for consumption and also affecting the wetland functions and most of these have been observed at Manguo wetland.

Eutrophication is another major impact on water caused by land use in the wetland basin. Intensive uses of fertilizers which are then leached into the water body leads to over production of algae leading to frequent algal blooms.

At Manguo wetland, pollution was evident in the water body as a result of dumping waste either directly into the water body or within the water basin. The trash was then carried to the open water by wind or flowing water. Examples of the waste materials observed were plastic bags, shoes, clothes, water bottles, paper which were visible in the water body and its basin.

5.6.4 Impacts on the landscape

Land utilization in the watershed was responsible for changes in the landscape. Clearing of land for settlement and agriculture has resulted in changes from a forest to woodland and now to open grassland. Introduction of large scale farming and planting of tree plantations has resulted in an open landscape with plots of exotic species such as Eucalyptus.

Use of the wetland as dumpsite also reduced its aesthetic value due to the presence of garbage dumps. Burning of the garbage in open uncontrolled situations has led to large open areas that turned black due to burning of the vegetation and soils. Though burning of garbage at Manguo wetland was stopped large areas of bare and black soil could still be seen during the study.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

The main objective of this study was to gain better understanding of the structure of the Manguo wetland vegetation community, its response to local soil and water conditions and how the vegetation had changed over time.

The results of this study help identify the current vegetation composition of the wetland, the current physical and chemical state of the wetland and the past vegetation composition and general structure of the wetland and its basin. There was a change in the vegetation composition and distribution of plant types over time showing how climate and human impacts have been of influence.

The plant community structure was determined to be open grassland with herbaceous vegetation ranging from the sedges in the flooded region to perennial grasses in the drier areas. The soil and water characteristics (nutrient levels) were measured and found to be at levels suitable for agriculture with soil moisture and acidity having the highest influence on the vegetation distribution. The vegetation composition was also realized to have changed from a predominantly woody ecosystem to open grassland at present.

The conservation efforts undertaken by MECONG and MLAO especially the fencing have produced some positive changes such as reduced waste dumping. The wetland is no longer an official dumpsite and there is no collection of bird eggs. However, unregulated grazing and harvesting of the sedges and grasses was still taking place. Monitoring of the wetland is necessary to ensure wise utilization and restoration activities so as to improve the health of the wetland.

According to Rey Benayas *et al.* (2009) restoration activities that enhance biodiversity are positively correlated with the increased provisioning of ecosystem services. Because the objectives of restoration activities have become increasingly focused on ecosystem services (Bullock *et al.*, 2011), it is important to account for the impacts of wetland use on biodiversity and ecosystem functioning. Therefore any activities taken to conserve a wetland should show how each aspect of the wetland will be protected since different stakeholders focus on different aspects of the wetlands. When the drivers of wetland degradation cannot be eliminated, restoration activities can still play a role in reducing negative impacts and enhancing benefits.

Removing the existing pressures on Manguo wetland and improving its resilience is the most effective method of coping with the adverse effects at this point. It is still a very productive wetland and further degradation should be stopped. Restoration which proceeds from the widely-cited definition of ecological restoration as “the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed” (SER, 2004) is probably the only alternative to deal with the current state of wetland. The Ramsar Convention defines restoration in its broadest sense, including activities that promote a return to previous conditions as well as those that improve the functioning of a wetland without necessarily seeking to return it to its pre-disturbance condition (Ramsar HB, 1991).

Restoration projects with indirect benefits should therefore be undertaken, for example using the area as a picnic and bird watching site as compared to harvesting plant material and drawing water which is not monitored. The change in vegetation structure from high forest species abundance to an open shrub and grassland is evidence of increase in human activities. When migration and settlements started there was high deforestation rate to make land available for settlement and urbanization. The fluctuation between the aquatic and dry indicator species, especially Cyperaceae and Poaceae levels, are evidence to changes in moisture levels. When the climate was wet the Cyperaceae levels would be higher than the Poaceae levels as opposed to when it was dry and the dry grasses would be more abundant than the aquatics. Collection of more samples, especially a deeper core and dating of the sediments would be critical to fill in gaps in climate, space and vegetation type coverage on a local and regional scale.

At regional scales, pollen data can be associated with vegetation and climate to provide information on how pollen percentages relate to large-scale vegetation and climate change patterns. Large-scale differences in vegetation type are also identifiable by their pollen signatures. Therefore conclusive ecological studies can be further enhanced by palynological information thus ensuring that the past and present and predictable future states are clearly understood.

6.2 Recommendations

Protecting and restoring wetlands should therefore be a critical element in national and global strategies to mitigate and adapt to climate change, ensure water, food and energy security, maintain human health as well as sustainable livelihoods. Restoring degraded wetlands increases the adaptive capacity of these ecosystems and their dependent communities to absorb and adjust to extreme events and other disturbances, such as floods, droughts, and sea level rise.

Wetland restoration activities that enhance resilience are therefore critical to the health and sustainability of socio-ecological systems. However, we must understand the nature of climatic and ecological changes that are likely to occur regionally in order to properly design wetland management and restoration plans at the mega-watershed level (Erwin, 2009).

Eastern and southern African countries are characterised by water stress brought about by climate variability and wider governance issues (Ashton *et al.*, 2002; UNESCO-WWAP, 2006). Significant progress has however, been recorded in some parts and that is why as according to Raymer (2006), Kenya needs to improve water security, sanitation and hygiene especially for the peri-urban and rural poor who often live in harsh environmental conditions. Therefore Kenya needs to take up the idea of recycling waste water to reduce pressure on the remaining fresh water resources. Test results of a study conducted by Raymer on water from a rural Kenyan spring during the year 2000 indicated a count of 35 *E. coli* per 100 ml (WHO potability criteria is zero), and the worst, 1800/100ml. That is why direct consumption of water from seemingly clean water bodies is extremely dangerous. Appropriate reuse of water not only reduces agricultural use of drinking water and water costs, but also increases food security and improves public health (Morel and Diener, 2006).

The lack of adequate data which could be used as evidence for whole-ecosystem shifts should be considered when concluding that the vegetation response is as a result of individualistic response in species assemblages rather than forests responding to climate change as single entities. Thus further ecological studies should be carried out to provide supporting evidence.

6.2.1 Recommendations for further research

- Further studies on mophometry, productivity and hydrology of the wetland should be carried out to facilitate better understanding of Manguo wetland. This will be essential in understanding the exact sources of Manguo water which would help in conservation of the catchment area.
- Research on vegetation, relationships modern pollen and climate should focus on under-represented and poorly sampled vegetation types, thereby completing the suite of potential analogues for late environmental conditions that existed.
- A zoological study would be essential in understanding the high faunal biodiversity observed at the wetland, a high number of frogs and insects were observed during the field work stage.

6.2.2 Recommendations for conservation

- Research data should be made available to the public so as to increase public awareness of the environment and conservation practices, for example the evidence of pollution is available and so are its impacts thus access to the wetland should be regulated and this can only be implemented by the land owners and county council.
- The immediate community should practice proper farming techniques so as to reduce soil erosion and leaching of fertilizer into the wetland. This will enhance wetland conservation activities.
- The MECONG and Limuru County council should organize wetland activities such as clean ups and talks involving the Manguo wetland stakeholders (land owners, county council, community members) which would lead to knowledge transfer and foster ownership of the resource thus continuity of conservation efforts**.**
- Reforestation efforts in the catchment should include a wide range of species including those that were present in the past such as *Croton, Acacia, Apodytes, Commiphora, Draceana* so as to promote biodiversity instead of monostands of *Pinus* and *Eucalyptus.*

6.2.3 Recommendations for management

- The MECONG and MLAO need to review their objectives and see whether any have been achieved and if not come up with reasons as to why they are not achieving them and develop better strategies. For example the efforts to turn the area into an ecotourism site cannot be implemented if the wetland is highly polluted thus a cleanup is necessary; the harvesting of the sedges is detrimental to the birds that use the wetland as a breeding site and that should be stopped.
- Regular monitoring by the major stakeholders (MLAO and Limuru county council) will ensure sustainable use of the wetland and cessation of any illegal activities taking place before the damage is too great. For example garbage dumping and excavation of soil for sale should be curtailed.
- Access to the wetland has to be regulated and enforced so as to stop the illegal activities taking place, this can only work if a fence is erected again and security guards hired to ensure there is no destruction of the fence.

6.2.4 Recommendations for policy action

The data shows that even under the land use pressure Manguo wetland is still a highly productive hence beneficial ecosystem. However the increased rate of soil erosion, leaching of nutrients and dumping of solid and liquid waste is unprecedented and wetland goods and services are decreasing. For example the Manguo open water is quite turbid and dirty which will affect the birds, frogs and even aquatic vegetation.

- Use of the wetland should be well monitored and fines/policies (restrict open access) put in place to punish the culprits who defy the orders.
- MECONG management committee should promote the policy guidelines on use and management of Manguo ensuring community participation.
- Land owners practicing farming near the wetland should regulate fertilizer use and ensure there is no season of bare ground as this is the major source of silt in the wetland. This can be enforced by the county council.
- Generally there should be enforcement of policies to protect wetlands and demonstrate to the communities the governments' commitment to protecting the wetland. For example, finding the culprits who uprooted the fence at Manguo wetland and having them prosecuted.

As stated by Musyimi (2011) the description of ecophysiological characteristics of wetland plants and other factors that determine their distribution by observation of the past and present situations that are similar to the expected future global environmental changes are needed to understand the fate of these wetland ecosystems. Such actions should be carried out not only at Manguo wetland but all wetlands especially the small sized wetlands that have not been studied and this will help in establishing a directory of our wetland resources.

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APPENDICES

Appendix 1: Plant species sampled in 2007 at Manguo wetland

No	**Species**	**Authority**	**Family**
1	*Achyranthus aspera*	L.	Amaranthaceae
2	*Laportea alatipes*	Hook. F	Urticaceae
3	*Pavonia urens*	Car	Malvaceae
4	*Galium simense*	Fresen	Rubiaceae
5	*Cyathula polycephala*	Baker	Amaranthaceae
6	*Crassula granvikii*	Mild Br.	Crassulaea
7	*Cyperus dercilema*	Steud	Cyperaceae
8	*Cyperus rigidifolius*	Steud	Cyperaceae
9	*Plectranthus barbatus*	Willd.	Lamiaceae
10	*Rumex bequestii*	Willd.	Polygonaceae
11	*Solanum aculeastrum*	Dund	Solanaceae
12	*Sphaeranthus suaveolens*	L.	Compositae
13	*Cycnium adonense*	Benth.	Scrophalariaceae
14	*Aspilia pluriesta*	Schweinf ex Engl	Compositae (Asteraceae)
15	*Typha domingensis*	Pers.	Typhaceae
16	*Cyperus dives*	L.	Cyperaceae
17	*Potamogeton*	L.	Potamogetonaceae

SOURCE: MACHARIA 2007

Appendix 2: Plant species identified between Aug 2011-March 2012 at Manguo wetland.

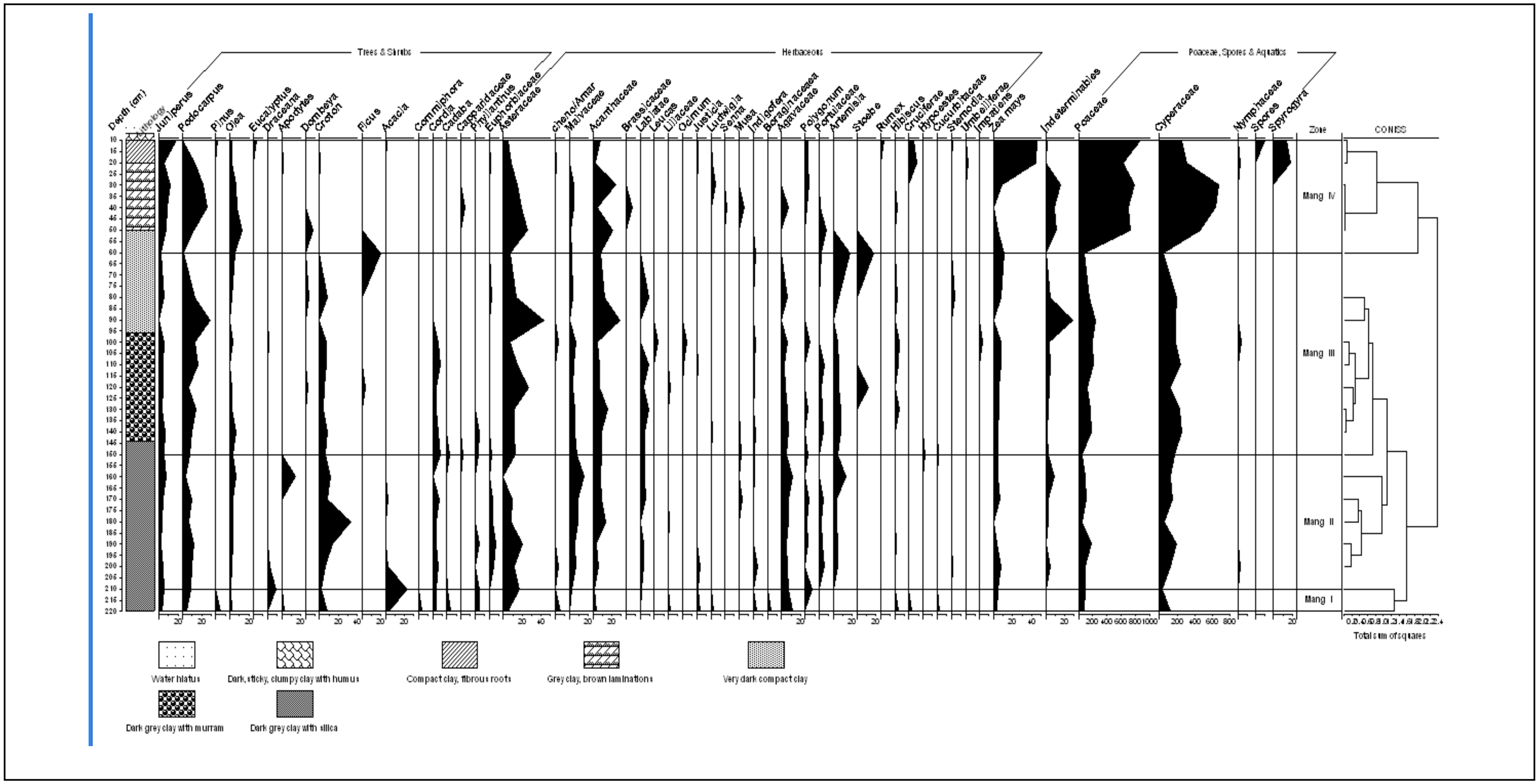
No	Species	Authority	Family
1	*Pennisetum clandestinum*	Schumach 1827	Poaceae
2	*Cyperus rotundus*	L.	Cyperaceae
3	*Cyperus exaltatus*	L.	Cyperaceae
4	*Digitaria ciliaris*	(L.) Scop	Poaceae
5	*Dichrocephala integrifolia*	O. Kuntze	Compositae (Asteraceae)
6	*Sphaeranthus gomphrenoides*	O. Hoffm.	Compositae (Asteraceae)
7	*Sphaeranthus bullatus*	Mattf.	Compositae (Asteraceae)
8	*Ethulia conyzoides*	L.	Compositae (Asteraceae)
9	*Lepidium bonariense*	L.	Brassicaceae
10	*Plantago palmata*	Hook. f	Plantaginaceae
11	*Gnaphalium declinatum*	Hilliard	Compositae (Asteraceae)
12	*Centella asiatica*	(L.) urb	Umbelliferae (Apiaceae)
13	*Cynodon dactylon*	(L.) Pers	Poaceae
14	*Rumex bequestii*	L.1753	Polygonaceae
15	*Uebelinia abyssinica*	Hichst.	Caryophyllaceae
16	*Hagenia abyssinica*	Willd.	Rosaceae
17	*Polygonum setaceum*	Rich	Polygonaceae
18	*Portulacca quadrifida*	L.	Portulacaceae
19	*Oxalis corniculata*	O. radicosa	Oxalidaceae
20	*Typha domingensis*	Pers.	Typhaceae
21	*Pavonia urens*	Cav.	Malvaceae
22	*Laportea alatipes*	Hook.f.	Urticaceae
23	*Aspilia pluriseta*	Schwein f.	Compositae (Asteraceae)
24	*Vernonia species*	Schreb.	Compositae (Asteraceae)
25	*Bidens pilosa*	L.	Compositae (Asteraceae)
26	*Solanum incanum*	L.(inc. S. richardii)	Solanaceae
27	*Datura stramonium*	L.	Solanaceae
28	*Potamogeton*	L.	Potamogetonaceae
29	*Acanthus*	L.	Acanthaceae
30	*Achyranthes*	L.	Amaranthaceae
31	*Veronica*	L.	Scrophulariaceae
32	*Kalanchoe*	Adans	Crassulaceae
33	*Dryopteris*	Adans	Dryopteridaceae
34	*Acacia melliferae*	Mill.	Mimosaceae

Appendix 3: Bird species identified at Manguo wetland between 1993 and 2006.

African Jacana	Garganey	Pied Kingfisher
African Spoonbill	Glossy Ibis	Pink-backed Pelican
Black Crake	Great Egret	Purple Swamphen
Black-crowned Night Heron	Green Sandpiper	Red-billed Teal
Black-headed Heron	Grey Crowned Crane	Red-knobbed Coot
Black Stork	Grey Heron	Ringed Plover
Blacksmith Plover	Hadada Ibis	Ruff
Black-winged Stilt	Hamerkop	Sacred Ibis
Cape Teal	Hottentot Teal	Southern Pochard
Cattle Egret	Knob-billed Duck	Spur-winged Goose
Common Greenshank	Little Egret	Three-banded Plover
Common Moorhen	Little Grebe	Whiskered Tern
Common Sandpiper	Little Stint	White-backed Duck
Common Snipe	Long-tailed Cormorant	White-faced Whistling Duck
Common Squacco Heron	Maccoa Duck	White-winged Tern
Egyptian Goose	Malachite Kingfisher	Wood Sandpiper
Eurasian Marsh Harrier	Marsh Sandpiper	Yellow-billed Duck
Fulvous Whistling Duck	Northern Pintail	Yellow-billed Egret
	Northern Shoveler	Yellow-billed Stork

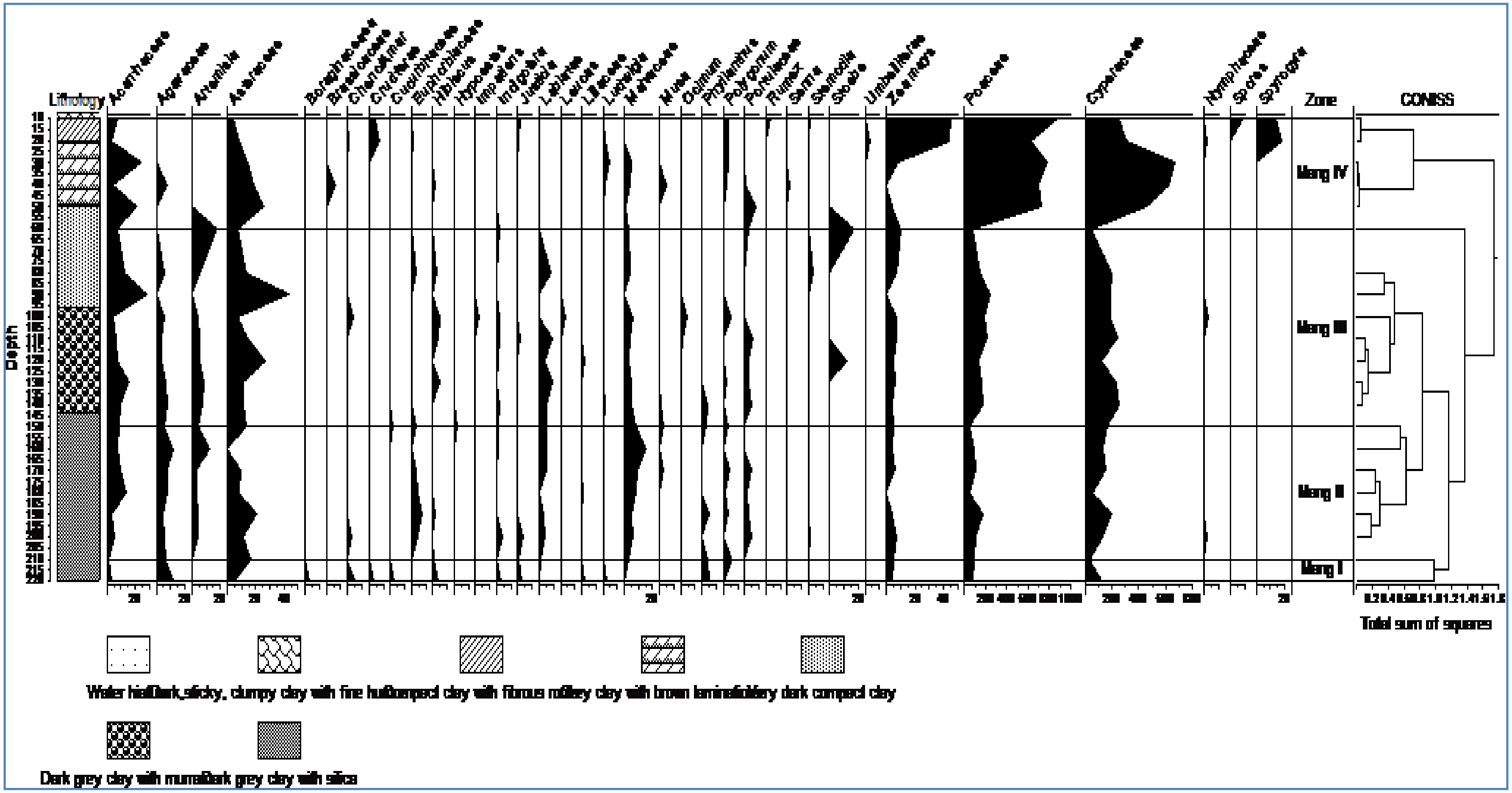
SOURCE: NATIONAL MUSEUMS OF KENYA – WETLANDS DEPARTMENT

Appendix 4: Complete Tilia diagram



A Tilia diagram showing the Manguo wetland pollen composition, the pollen is classified into trees, herbaceous vegetation and aquatics. It also shows the change in soil profile with depth.

Appendix 5: Herbaceous vegetation Tilia diagram



The herbaceous vegetation represented by the pollen from the Manguo wetland core.

Appendix 6: Summary of the DCA results relating to Figure 4.3

Axes	**1**	**2**	**3**	**4**	**Total Inertia**
Eigenvalues	0.349	0.82	0.045	0.07	0.810
Length of gradient	3.365	2.035	1.026	1.132	-
Cumulative percentage variance of species data	43.1	53.2	58.8	59.6	-
Sum of all unconstrained eigenvalues	-	-	-	-	0.810

Appendix 7: Summary of the CCA results relating to Figure 4.4

Axes	**1**	**2**	**3**	**4**	**Total Inertia**
Eigenvalues	0.327	0.173	0.092	0.081	0.766
Species-environment correlations	1.000	1.000	1.000	1.000	-
Cumulative percentage variance of species data	42.7	65.4	77.3	88.0	-
Cumulative percentage of species-environment relation	42.7	65.4	77.3	88.0	-
Sum of all unconstrained eigenvalues	-	-	-	-	0.766
Sum of all canonical eigenvalues	-	-	-	-	0.766

Appendix 8: Land use practices and their impacts on Manguo wetland

WETLAND COMPONENT	LAND USE	IMPACTS	ECOLOGICAL CONSEQUENCES
Catchment area	Subsistence agriculture	• Soil erosion. • Leaching. • Grazing.	• Reduction of water volume. • Eutrophication of the water basin. • Soil erosion.
	Waste disposal	Burning	• Air and land pollution. • Destruction of soil biota.
Water shed	Poor agricultural practices.	• Soil erosion. • Leaching. • Siltation.	• Loss of fertility. • Eutrophication. • Soil erosion. • Reduction in wetland volume.
	Grazing	Soil compaction.	• Introduction of new species. • Depletion of preferred species.
	Waste disposal	Burning	Soil degradation.
	Dumping.	Pollution.	• Reduction in ecosystem health. • Loss of species. • Eutrophication
Vegetation	Harvesting of reeds/ sedges	Elimination of target species.	Depletion of species.
	Grazing	Depletion of vegetation	Loss of wetland species.
		Introduction of new species from the dung.	Invasive species.
		Trampling of plants and soil.	
		Changes in nutrient dynamics from the dung input.	Eutrophication.
Water	Water harvesting.	Drawing of water.	Reduction of water level.
	Dumping.	Pollution.	Lowering of water quality.
	Agriculture	Leaching.	Eutrophication.
Soil	Sale of soil	Digging of pits.	Land degradation
Birds	Harvesting of sedges.	Destruction of the birds' habitat and breeding ground.	Reduction in avifaunal biodiversity.
	Collecting bird eggs.	Reduction in bird numbers.	Interference with bird breeding and population patterns.

Appendix 9: Selected taxa with value as indicators of past vegetation.

FAMILY	GENUS	LIFEFORM	ECOLOGY
Cupressaceae	*Juniperus*	Tree	Can grow up to 40m tall. Found in drier upland forests associated with Podocarpus, *Olea* or *Croton*. Between 1800-2950m.
Podocarpaceae	*Podocarpus*	Tree	Evergreen tree, trunk up to 2m across, found in drier upland forests and is often associated with *Juniperus*.
Oleaceae	*Olea*	Tree	Evergreen shrub or tree 3-24m. Found in dry upland evergreen forest (edges, remnants) often in association with *Juniperus*. Maybe co-dominant.
Icacinaceae	*Apodytes dimidata*	Tree/shrub	3.5-25m tall evergreen found in upland dry forests (edges/remnants).
Euphorbiaceae	*Croton*	Tree	3-25m tall, found in moist or dry evergreen upland forests, also riverine forests or woodlands.
Moraceae	*Ficus*	Trees/shrub/vines	Native throughout the tropics they occupy a wide variety of niches but most are evergreen, deciduous species endemic to temperate areas are found in high latitude. Fruits from the fig tree are edible. Are associated to the wasp from family Agaonidae for pollination.
Mimosaceae	*Acacia*	Tree	Perennial tree found in dry areas that can manifest as either a multi trunked bush to 7m or a small single trunked tree up to 9m
Compositae/ Asteraceae	*Artemisia afra (Willd)*	Woody herb or shrub.	Grows to between 0.7-2.5m colonizing burnt areas. Common in heath zone, grassland, upland bush land and forest edges sometimes forming pure stands. At 1550-3750masl.
Malvaceae	*Hibiscus*	Woody herb or shrub.	0.7-3m tall, found in riverine, forest margins, thickets, bush land.
Poaceae	*Zea mays*	Woody herb	Maize can vary between 2.5m-12m depending on the variety, maize is grown all over the world.
Cyperaceae	*Cyperus exaltatus C. rotundus*	Herb/sedge	Wetland sedges, they are annual or perennial plants, mostly aquatic growing in still or slow-moving water up to 0.5 m deep. They greatly in size, with small species only 5 cm tall, while others can reach 5 m in height.

Appendix 10 a): Manguo wetland soil macronutrient levels

		Q3N	Q4N	Q11E	Q12E	Q19S	Q20S	Q29W	Q30W
pH	Top	5.21	5.28	5.53	5.36	5.12	5.51	5.13	5.07
	Sub	5.74	5.67	5.89	5.44	5.42	5.68	5.15	5.52
Org Carbon (%)	Top	3.2	2.96	4.36	8.02	1.97	5.55	2.44	2.3
	Sub	1.22	1.37	2.86	0.97	2.46	2.22	1.68	0.89
Total N (%)	Top	0.48	0.29	0.51	0.8	0.18	0.6	0.24	0.22
	Sub	0.12	0.14	0.28	0.11	0.25	0.3	0.17	0.19
P (ppm)	Top	46	26	41	30	36	30	51	38
	Sub	45	37	23	63	60	32	51	22
K (me %)	Top	1.38	0.74	1.6	2.08	1.3	2.08	1.44	0.5
	Sub	1.16	0.68	1.56	1.26	2.08	2.04	1.5	0.38

Appendix 10 b): Manguo wetland soil micronutrient levels

		Q3	Q4	Q11	Q12	Q19	Q20	Q29	Q30
Ca (me %)	Top	7.6	6	8.8	9.8	5	8.6	5.8	3.4
	Sub	8.4	8.6	8	6	9	9	7.8	2.5
Mg (me %)	Top	1.63	2.27	2.43	1.86	1.7	2	1.5	0.11
	Sub	2.52	1.8	2.23	2.14	1.8	2	1.77	0.17
Mn (me %)	Top	0.85	0.43	0.67	0.48	0.36	0.41	0.39	0.76
	Sub	0.32	0.15	0.39	0.36	0.31	0.26	0.26	0.73
Cu (ppm)	Top	1.87	1	1.51	1.74	1.75	1.6	2	1.88
	Sub	0.95	0.74	1.44	1.63	1.26	1.35	1.8	1.37
Fe (ppm)	Top	246	994	634	1569	354	699	1336	233
	Sub	504	277	419	574	483	462	761	125
Zn (ppm)	Top	38.9	7.47	17.9	53.8	16.8	28.6	13.7	3.23
	Sub	3.44	2.18	15.9	16.4	11.9	12.6	11	6.26
Na (me %)	Top	0.78	0.68	0.92	1.4	0.76	2.08	1	0.4
	Sub	0.9	1.06	0.94	0.82	1.52	2	1.08	0.32

Appendix 10 c): Manguo wetland soil moisture and texture grades.

	Level	% Sand	% Silt	% Clay	Texture Grade	% moisture (W/W)
Q 3	**Top**	12	40	48	**C**	65.8
	Sub	12	34	54	**C**	68.7
Q 4	**Top**	10	62	28	**SCL**	60.3
	Sub	14	26	60	**C**	26.7
Q 11	**Top**	14	36	50	**C**	40.2
	Sub	12	30	58	**C**	54.4
Q 12	**Top**	32	30	38	**CL**	69.9
	Sub	10	22	68	**C**	65.1
Q 19	**Top**	10	30	60	**C**	56.2
	Sub	12	20	68	**C**	19.6
Q 20	**Top**	22	30	48	**C**	53.9
	Sub	12	26	62	**C**	86.2
Q 29	**Top**	16	30	54	**C**	23.6
	Sub	14	30	56	**C**	60.0
Q 30	**Top**	18	26	56	**C**	57.7
	Sub	20	28	52	**C**	61.5

Key: C-Clay L-Loam S-Sand CL-Clay loam SCL-Sand clay loam

Appendix 11: Manguo wetland water characteristics and nutrient levels

Parameter	Permanent pool	Temporary pool
Ph	6.09	5.89
Temperature	22.1	20.83
Conductivity (mS/cm)	0.13	0.15
Sodium (me/litre)	0.55	0.63
Potassium (me/litre)	0.21	0.20
Calcium (me/litre)	1.25	1.92
Magnesium (me/litre)	0.15	0.22
Carbonates (me/litre)	N/D*	N/D*
Bicarbonates, (me/litre)	2.11	2.66
Chlorides (me/litre)	10.1	9.25
Sulphates (me/litre)	2.33	1.60
Sodium Absorption Ratio	0.66	0.61

*Carbonates were not detected.