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ASSESSMENT OF ECOSYSTEM SERVICES IN NATURAL WETLANDS AND RICE FIELDS IN NYANDO FLOODPLAIN, KENYA

Master of Science Thesis

by

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DECLARATION AND RECOMMENDATION

DECLARATION

This thesis is my original work and has not been submitted or presented for examination in any institution.

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RECOMMENDATION

This thesis has been submitted with our approval as supervisors for examination according to Egerton University regulations

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ABSTRACT

Natural wetlands are crucial ecosystems capable of providing provisioning, regulatory and cultural ecosystem services (ES). However, globally, wetlands are constantly under threats of degradation of their functions and loss or reduction of wetland coverage area, as a result of agricultural intensification due to demands for food production. Natural wetlands in Nyando floodplain are no exception as a result of conversion into rice fields. Such conversions may compromise some of the ecosystem services (ES) (benefits people obtain from ecosystems) in natural wetlands even though rice fields also deliver ES which are important in supporting livelihoods in the area. Therefore, this study aimed to assess ES in Ombeyi natural wetland and rice fields in Nyando floodplain to quantify ES in both systems despite the continuous conversion influence on ES delivery to the community. This study was done for a period of four months running between December 2014 and March 2015. Questionnaire survey and Focus Group Discussion were used to assess provisioning and cultural ecosystem services in Ombeyi natural wetland and rice fields using indicators of measurements for ES such as rice yield, fish quantity, price and aesthetic value among others. The effect of water purification as an ecosystem service was evaluated by analysis of water quality changes through *in-situ* measurements of physico-chemical parameters, nutrients and sediments content in water from River Ombeyi, Ombeyi natural wetland, rice fields and drainage canals. Water samples were collected twice a month in the inlets and outlets of rice fields and the natural wetland, rice fields' drainage canals and River Ombeyi for nutrients and total suspended solids (TSS) analysis using standard methods. The results showed that the natural wetland had retention of 19.6% for nitrate-nitrogen, 28.8% for Soluble Reactive Phosphorus, 50% for total phosphorus, 19.1% for total nitrogen and 45.6% for (TSS). In the rice fields the retention of 58.21% for TSS, 36.89% for nitrate, TN 35.72%, SRP 79.16% and TP 60.52% were obtained. The chi-square test showed that rice fields retained more nutrients and sediments compared to the natural wetland ($p<0.05$) except for ammonium in both systems which were not significantly different ($p>0.05$). Rice fields were observed to be source of ammonium while natural wetlands acted as transformers. Cultural and provisioning services were graded as low both in the natural wetland and rice fields mainly due to continuous conversion of the natural wetland into rice fields.

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LIST OF ABBREVIATIONS AND ACRONYMS

DO	Dissolved Oxygen
EC	Electrical Conductivity
ES	Ecosystem Services
FGD	Focus Group Discussion
GF/C	Glass Fibre Filter
GIS	Geographical Information System
GPS	Geographical Positioning System
H_2SO_4	Sulphuric Acid
MEA	Millennium Ecosystem Assessment
MWENR	Ministry of Environment and Mineral Resources
N	Nitrogen
NH_4-N	Ammonium-Nitrogen
NIB	National Irrigation Board
NO_2-N	Nitrite-Nitrogen
NO_3-N	Nitrate-Nitrogen
P	Phosphorus
SRP	Soluble Reactive Phosphorus
TEEB	The Economics of Ecosystems and Biodiversity
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
VIRED	Victoria Institute for Research on Environment and Development

CHAPTER ONE

INTRODUCTION

1.1 Background information

Floodplains in river basins are utilized globally for agricultural production due to their high fertility resulting from regular deposition of organic matter-rich soil during flooding events (Verhoeven and Setter, 2009; Rouquette *et al.*, 2011). Apart from agricultural systems, floodplains also have a variety of other ecosystems that perform multifunctional processes which ultimately provide a wide range of economic, social and environmental benefits to the society (Rouquette *et al.*, 2011). Such gains derived from ecological activities of ecosystems are referred to as Ecosystem Services (ES) (MEA, 2005). The ES are typically generated when ecosystem components and their processes interact (De Groot, 1992). Nevertheless, the use of floodplains primarily for agricultural production frequently lead to a compromise of ES derived from other ecosystems such as wetlands due to conflicting demands on water resources and land (Morris *et al.*, 2009).

The consideration of ES as part of the benefits derived from ecosystems provides a suitable framework by which the society evaluates the importance of natural environments such as wetlands and provides a basis for informed decisions on conservation and sustainable management strategies of natural ecosystem resources and services. The ES concept is a potential tool for linking human welfare and the ES derived from such natural environments. This creates a common platform for communicating the value of ecosystems to stakeholders in the society (Carpenter *et al.*, 2009; Grêt-Regamey *et al.*, 2013).

The ES concept is progressively becoming more useful in decision making in management of natural resources. In spite of this popularity, quantification and execution of the ES approach has been a major challenge for ecosystem science (Wallace, 2007). The major drawback is the measurement of ES, which is often done through monetary valuation. However, attaching a price tag to ES is frequently unsatisfactory, since it focuses mainly on the economic benefits, dependent on pricing context but lacks suitable pricing methods for non-market goods and services (Spangenberg and Settele, 2010; Ghaley *et al.*, 2014). Furthermore, non-market services such as cultural, regulatory and supporting services are often difficult to measure or give value directly. Nevertheless, indicators of ES such as nutrient retention for water purification, crop yield or quantity and price for provisioning services and aesthetic value for cultural services among others, provide an alternative avenue through which ES may be measured (Swallow *et al.*, 2009; Rouquette *et al.*, 2011; Burkhard *et al.*, 2012; Russi *et al.*, 2013).

Wetlands as one of the ecosystems which often occur in floodplains have been studied widely in many parts of world (Kanyiginya *et al.*, 2010; Rongoei *et al.*, 2013; Russi *et al.*, 2013). The significance of their ES in support of livelihoods was one of the key components of the Millennium Ecosystem Assessment (MEA) and the Economics of Ecosystems and Biodiversity (TEEB) (MEA, 2005; TEEB, 2011; Russi *et al.*, 2013). According to MEA (2005) and TEEB (2011), wetlands sustain the livelihoods of many people both directly and indirectly by supplying provisioning (e.g. fibre, water, food, fuel wood, natural medicines), regulatory (e.g. flood control, water quality improvement), supporting (e.g. nutrient cycling, primary production), and cultural services (e.g., recreation, aesthetics, education). In spite of the importance of these services to the society, wetlands globally have been identified as one of the most threatened ecosystems particularly due to demands for food production, through agriculture coupled with challenges in implementation of water management strategies. This is attributed to human population increase and the need for economic developments (MEA, 2005).

The Nyando River Natural wetlands in Kano floodplain, Kisumu County, Kenya are threatened by degradation due to over-exploitation and conversion into farmland which may have compromised and even reduced in their ES functions (Owino and Ryan, 2007). Furthermore, over the past five decades the area covered by the natural wetlands has largely declined through conversion into farmland especially paddy rice fields, sugarcane and arrow roots (Swallow *et al.*, 2007; Obiero *et al.*, 2012a). This study assessed the current (2014-2015) delivery of ES in one of the Nyando Basin natural wetlands; Ombeyi and adjacent rice fields in the Kano floodplain. Selected biological (rice yields and fish quantity), and physico-chemical (nutrient and sediment retention) as well as socio-cultural (aesthetic value) indicators were used to measure the magnitude of ES supply in both natural wetlands and rice fields. The quantification of ES for Ombeyi wetland provided valuable information for scientific advancement and decision making regarding the sustainable management of the Nyando floodplain and its natural wetlands and rice fields.

1.2 Statement of the problem

Over the past five decades, wetlands in Nyando floodplain have been facing threats from agricultural developments such as their conversions into rice irrigation schemes. The implication is that ES provided by these inland natural wetlands to local communities and the Lake Victoria ecosystem are lost or compromised. In the 1960s and 70s, conversion of 67 % of Nyando wetlands into rice fields has been documented. Data on the current (2015) coverage of natural wetlands and rice fields in the floodplain is lacking since some of the agricultural expansion are not only developed by government agencies but also by local communities with minimal documentation. Although rice production of approximately 3 tonnes ha^{-1} $year^{-1}$ has been recorded in Nyando floodplain, the extent to which these rice fields can provide ES is generally unknown. The assumption is that development of rice schemes have occurred at the expense of ES provided by natural wetlands lack scientific information that needed to help improve existing knowledge and wetland management gaps in the natural wetlands and associated agro-ecosystems.

1.3 Objectives

1.3.1 General objective

To assess Ecosystem Services (ES) in natural wetlands and rice fields in Nyando River basin of Kano floodplain.

1.3.2 Specific objectives

1. To evaluate and compare the provisioning, cultural and regulatory (water purification) ES in Ombeyi natural wetland and rice fields in Nyando floodplain**.**
2. To determine nutrients and total suspended solids retention capacity of Ombeyi natural wetland and rice fields in Nyando floodplain.

1.4 Hypotheses

1. H_0: Conversion of natural wetland into rice fields has not significantly affected the supply of provisioning, cultural and regulatory ES in Nyando floodplain.
2. H_0: There is no significant difference in the capacity of Ombeyi natural wetland and associated rice fields in retaining nutrients and total suspended solids.

1.5 Justification

Increasing agricultural production to achieve food security and rural prosperity in an environmentally sustainable manner is one of the Kenya's government goals in Vision 2030. Natural wetlands are highly fertile systems due to accumulation of organic matter or peat, and thus are valuable for agricultural production. This predisposes these ecosystems to agricultural expansion which in turn may result to loss of their ES and hence directly influencing the livelihoods of floodplain communities. The loss and degradation of natural wetlands as a result of their conversion into rice fields and irrigation developments in the lower Nyando River basin in Kano floodplain is occurring uncontrollably. Though such agricultural developments have increased food production, the magnitudes of ES supplied by both systems in the floodplain need to be well studied, understood and documented to enable continued monitoring for better management. Such studies will also enable availability of vital information needed for decision making towards integrated and sustainable management of natural wetlands and rice fields in the Nyando floodplain a situation that justified this study since as an important source of well documented scientific baseline data.

CHAPTER TWO
LITERATURE REVIEW

2.1 Wetlands and their global status

Wetlands are defined by Ramsar Convention as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water the depth of which at low tide does not exceed six metres". They are characterized by the presence of water either at the surface or within the root zone, hydric soil and flood tolerant vegetation (Mitsch and Gosselink, 2000; Zedler and Kercher, 2005).

The area covered by wetlands globally varies significantly. Yoon (2009) states that wetlands globally, cover a total area of approximately 570 million ha which translates to roughly 6 % of the earth surface. According to Zedler and Kercher (2005), wetlands occupy 9 % of the land area. These variations in global estimates of wetlands coverage are attributed to challenges in mapping and monitoring their change over time (Junk *et al.*, 2013). The lack of data on wetland coverage is not exceptional to Kenyan scenario where the actual area covered by wetlands is unknown due to lack of wetlands inventory (Kenya Wetlands Forum, 2010). It is estimated that wetlands cover approximately 3 to 4% of the total landmass, which is roughly 14,000km^2 of the Kenyan land surface area. However, during rainy seasons the wetlands increase up to 6% of the land area (Kenya Wetlands Forum, 2010; Ministry of Environment and Mineral Resources, 2012).

2.2 Wetland loss and agriculture

Globally, approximately 50 % of wetland areas had been lost in the twentieth century due to their reclamation and conversion into agricultural land through drainage (MEA, 2005). The remaining wetlands are under threat of loss and degradation from both direct and indirect human activities. Many wetlands in different countries are facing similar challenge due to growing human population and increasing need for economic developments (MEA, 2005; Junk *et al.*, 2013). In Kenya, Owino and Ryan (2007) reports a 50 % loss of papyrus wetlands in parts of Lake Victoria basin over the period of 1969-2000 due to agricultural expansions and overexploitation through harvesting of papyrus biomass. Furthermore, Swallow *et al.* (2007) reported 67% loss of Nyando wetlands between 1960s and 1970s due to their conversion into rice fields. Despite these losses of natural wetland areas, man-made wetlands such as rice fields and fish ponds have increased the total area covered by wetlands in some countries for example in south east Asian countries (Yoon, 2009; Junk *et al.*, 2013). In Nyando floodplain however, there is a trade-off between natural wetlands and rice fields ecosystems. Swallow *et al.* (2009) reports declining coverage of natural wetland areas in entire River Nyando basin from 1.93 % in 1991 to 0.40 % in 2006. Meanwhile, during the same year, rice fields increased by 0.45 %.

Rice (*Oryza sativa*) is a semi-aquatic crop grown primarily in flooded fields or paddies and is the staple food for over half of the world's population. It is one of the largest irrigated crops and ranks second to wheat as the most widely grown crop globally (Yoon, 2009). In Kenya, it is the third most grown crop after wheat and maize with paddy rice culture as the most predominant technique for growing rice (Mati *et al.*, 2011).

Paddy rice-fields cover approximately 18 % of the total wetlands on earth. As part of human-made wetlands, paddy rice fields are important being, second in size (130M ha) after freshwater natural wetlands (Yoon, 2009). They have also contributed to increase in extent of area covered by wetlands. In Kenya, particularly in Nyando river basin, the Kano floodplain is part of paddy rice fields which covered 0.45 % of the basin in the year 2006 (Swallow *et al.*, 2009). Thereafter, the actual data on paddy rice fields' coverage up to date is however sporadic or totally lacking and hence partly the reason for this study.

2.3 Ecosystem services concept

Ecosystem services are generated by ecosystems functions; production, provisional, regulatory and cultural, which are in turn dependent on biophysical structures and processes (De Groot, 2006). Utilization of a service or good provides benefits which can be quantified using non-monetary or economic-monetary terms. This infers that ES and functions are distinguishable. Ecosystem services are benefits that people derive from ecosystems while ecosystem functions are interactions of components and processes to provide goods and services (De Groot, 1992; MEA, 2005; TEEB, 2011; Russi *et al.*, 2013).

The ES concept is not new and has been documented for many decades. However, it was not until the publication of the Millennium Ecosystem Assessment (MEA) that made the approach popular among researchers (MEA, 2005; Rouquette *et al.*, 2011). Through MEA publications the efforts to put the concept into practise has increased significantly. Frameworks for evaluation of ES have been developed and the approach has been studied widely for both wetland ecosystems and agricultural systems (Boyd and Banzhaf, 2007; Zhang *et al.*, 2007). In addition, studies have been undertaken to examine ES provision under a range of alternative land-use scenarios, in order to understand synergies and trade-offs in the fragile ecosystem management (Posthumus *et al.*, 2010).

Although the concept has gained significant interest among researchers, it is increasingly contested and objected due to its classification, distinction between ES and functions, anthropocentric focus, emphasis on exploitative human-nature relationship and overlap of ES with biodiversity among others (Fisher *et al.*, 2009; Schröter *et al.*, 2014). Despite these critiques the concept remains an important tool in the sustainable management of natural resources. This is because the ES concept promotes understanding of multiple benefits from ecosystems to society and its use can facilitate collaboration between various stakeholders (MEA, 2005).

2.4 Assessment and quantification of ES

There are several ways of measuring ecosystem services to the society. According to Burkhard *et al.* (2012) ES has diverse attributes for measuring and that may be used to describe indicators of ecosystem goods and services. These range from measures of extent, state and condition of underlying system such as vegetation cover, ecological health, number of species; measures of ecosystem functions and processes such as water purification and nutrient retention as well as measures describing utilization.

Many people depend on ES for their survival and well-being and thus it is crucial to assess and quantify the supply of these services. Assessment and quantification of ES is also a key step towards policy formulation and decisions making in development of management strategies of natural resources and ecosystems, especially at local scale where in most cases the information are often lacking (Turner and Daily, 2008). Quantification of ES is most frequently conducted prior to evaluation of trends and trade-offs coupled with monetary valuation. However, most ES are not quantifiable directly even though majority of studies on quantification of ES have been done using economic valuation or monetary methods (Burkhard *et al.*, 2012). Thus, quantification of some ES requires use of non-monetary methods such as biophysical assessments based on indicators in order to identify whether or not the services are utilized sustainably or are still being provided by a particular ecosystem (Burkhard *et al.*, 2012; Egoh *et al.*, 2012). Whereas ES providing goods can be quantified directly, ES such as cultural, supporting and regulatory services cannot be easily quantified directly and researchers have to rely on indicators such as vegetation cover, number of tourists in an area and quantity of goods among others or proxies generated data from models for their quantification (Maes *et al.*, 2011; Egoh *et al.*, 2012).

Provisioning services quantification entails determination of the quantity of goods harvested in the ecosystem, in physical units (Hein *et al.*, 2006). Production (yield/biomass) and products' (e.g. crops, mats and fish) market prices are suitable indicators for provisioning ES (Burkhard *et al.*, 2012). In studies done by ES Swallow *et al.* (2009) on provisioning ES provided by Yala and Nyando River Basins data from various agricultural sectors in Kenya are used to quantify agricultural production in terms of yield and price for various crops. In relation to natural wetlands and rice fields, provisioning services such as rice yield, fish catch quantity and market prices of various goods derived from both systems are applicable in quantification of the ES and were applied in this study. In addition, the area under production provides an appropriate indicator for the provisioning ES and can potentially be used for evaluating their spatial distribution (Maes *et al.*, 2011). Thus, provisioning ES appears to be fairly easy to quantify when monetary terms are applied. However, changing market prices and supplies or trade patterns must be taken into consideration (Burkhard *et al.*, 2012).

Regulatory services (e.g. water storage, soil erosion control and climate regulation and water purification) quantification is difficult and majority of assessment is based on model calculations (Jørgensen and Nielsen, 2012). The challenge on their quantification is attributed to the fact that regulatory services relate to the processes and functions of ecosystems which are in turn dependent on ecological health or integrity of a system. According to Dale and Polasky (2007) functions of ecosystems are usually complicated to measure but structures and compositions are quantifiable. Such information may reveal their functional properties in the ecosystem such as carbon storage. However, some studies have done quantification of regulatory ES using percentages or mass of nutrients and sediment retained from an ecosystem as indicators for water purification (Posthumus *et al.*, 2010; Russi *et al.*, 2013). In this study water purification of natural wetlands and rice fields were measured using quantity of nutrients and sediment retained in both systems.

Cultural services assessments are dependent on people's understanding of ecosystem, and the values each individual attach to a particular ES or particular features of ecosystem. Cultural ES are subjective since they depend on observers' judgement as opposed to ecosystem condition. This makes their quantification and development of indicators challenging (Posthumus *et al.*, 2010). Burkhard *et al.* (2012) nonetheless, recommends recreation, aesthetic and intrinsic values of biodiversity to be quantified spatially using number of tourists visiting an area, endangered species or rare habitats among others. Also, assessing number of people benefitting from the service, number of scientific publications and educational excursions in a particular ecosystem have been proposed as indicators by Russi *et al.* (2013). Posthumus *et al.* (2010) on the other hand quantifies cultural services by scoring landscape value or recreational use of ecosystems. In this study cultural services were measured by scoring the frequency of tourists, number of educational excursions recreational uses, spiritual/religious and aesthetic value of both natural wetland and rice fields to the community.

Supporting services such as soil formation, nutrient cycling and primary production characterize the ecological processes which underpin the existence of other services. Thus, it is often not quantified in many studies under rationale of double counting of other ES due to its features being reflected on other ES (Hein *et al.*, 2006). For instance, growth of vegetation is dependent on soil formation, primary production and through vegetation growth or cover, other ES such as cultural services (aesthetic value) and regulatory services (sediment retention) can be easily quantified. However, Ghaley *et al.* (2014) has reported using number and weight of earthworms as indicators of soil formation. In addition, when supporting services are classified as habitat services, habitat and species conservation value may be used as the indicators of the supporting services (Posthumus *et al.*, 2010). However, even under the classification of habitat services, it still overlaps with cultural services; for example aesthetic value.

2.5 Measurement of Indicators of Ecosystem Services (ES) in wetlands

Wetland ecosystems have been identified to provide numerous valuable ES which both directly and indirectly contribute to human well-being (Zedler and Kercher, 2005; Verhoeven *et al.*, 2006). In the Sub-Saharan Africa, wetlands are known to support the livelihoods of many people through supply of many ES such as food, water, fibre and fuel among others (Rebelo *et al.*, 2010; Rongoei *et al.*, 2013).

Water purification as an ES delivered by wetlands is important in reducing nutrients and sediments loadings into the receiving water bodies and thus enhancing water quality (Verhoeven *et al.*, 2006; Hefting *et al.*, 2013). This ES is measurable through application of indicators for water purification such as nutrients and sediment retention quantified either as percentage or gravimetrically (Russi *et al.*, 2013). However, in case a natural wetland is acting as a source of nutrients rather than a sink, the amount of nutrient leached from the system are measurable but it is important to note that the leaching is not a service but a disservice of the wetland (Posthumus *et al.*, 2010). From studies done by Kanyiginya *et al.* (2010) wetlands retain NH_4-N, NO_3-N, and TN at 21%, 98%, and 35% respectively. The implication of this is that wetlands are sinks rather than sources of nutrients. Also, area under wetlands vegetation are measurable as an indicator of water purification through the presumption that vegetation slows down water velocity, increasing sediment retention and nutrients uptake (Swallow *et al.*, 2009). Wetland area under wetland vegetation (size), can be obtained from Geographical Information System (GIS), remote sensing and even Geographical Position System (GPS) (Burkhard *et al.*, 2012). For instance, Naidoo *et al.* (2008) uses proxy data to map various ES globally. Nevertheless, in this study, area under wetland vegetation was not used to quantify water purification ES because of challenges in hydrological alterations of the river flowing through the natural wetland. In most cases the river flows into the wetland for a few metres before it is diverted into the rice irrigation scheme. This may limit interactions between wetland vegetation and water carrying pollutants. Thus, use of natural wetland vegetation as an indicator was inappropriate in this study. Instead the amount of nutrients and sediment retained were used as indicators of water purification.

Wetlands provisioning ES such as fish supply, fuel wood, water, wild game, medicinal plants and fibre is normally quantified using market price and quantity of the goods as well as area coverage of the goods. In this study wetland provisioning services such as making mats, fish catches and wild game meat supply among others were quantified using different units of measurements such as quantity, price and availability.

Cultural services from wetlands are subjective and depend on individuals' preferences and values attached to the system. Wetlands have a long history of being perceived as "wastelands" and this notion has led to loss of significant proportion of wetlands worldwide (Junk *et al.*, 2013). According to MEA (2005) wetlands are "useful " systems which provides beautiful landscapes and rich biodiversity thus delivering recreational, aesthetic, educational and spiritual ES which contributes to human well-being, cultural identity and economy. Moreover, wetlands provide important habitat for organisms like water birds, amphibians, fish and mammals among others (MEA, 2005). Due to loss of wetland areas many of the organisms are either threatened or get extinct. For instance, MEA (2005) reported that roughly 20 % of the world's 10,000 described freshwater fish species have been listed as threatened, endangered, or extinct in the last few decades. Therefore, assessment of the area covered by natural wetland vegetation and its ecological health potentially conveys useful information on the habitat ability to provide refuge and nurseries for organisms as well as provision of other ES. This infers that wetlands provide habitat for organisms and thus delivering cultural services such as recreation, aesthetics and even tourism. In studies done by Posthumus *et al.* (2010) cultural services in floodplains in England were quantified using scoring method for the preferred landscape.

2.6 Measurement of Ecosystem Services (ES) indicators in rice fields

Paddy rice fields have the potential to partially compensate for the loss of ES provided by the lost natural wetlands since they not only provide food but also have various other multi-functions (Yoon, 2009; Natuhara, 2013). These include: soil erosion control, flood control, water purification, ground water recharge and birds' habitat. At the same time, water within the irrigation or drainage canals often provide services such as livestock watering, domestic water provisions and fisheries which are hardly recognized (Bakker and Matsuno, 2001).

Rice fields' ES of water purification are quantifiable by the use of same indicators as natural wetlands, that is, nutrient and sediment retention. According to Eom (2001), rice fields are capable of retaining P and N ranging from 27-65% and 52-66% respectively. However, comparative studies on water purification capacity in relation to nutrients, Total Suspended Solids (TSS) and heavy metals of rice fields and natural wetlands have not been documented. Furthermore, studies on rice fields and natural wetlands are often conducted separately and therefore, lack of such comparative information makes this study potentially important in forming baseline data on both systems.

Provisioning services derived from rice fields such as rice production and fish harvesting are quantifiable through production function using indicators such as crop yield, price, quantity and area under production (Swallow *et al.*, 2009; Natuhara, 2013). In this study rice yield, area under production, fish quantity and price were used as indicators of measurements of provisioning services. Cultural services on the other hand have been highly reported in Asian countries, where terrace paddies attract people, such as exhibition being held in the paddies. Also, farmers continue growing rice despite the low income from rice production due to traditional attachments concerning rice paddy fields inheritance across generations and sense of identity from the landscape (Natuhara, 2013). Rice fields have been reported to play an important role as habitat for plants, water birds, fish and other organisms and therefore contributing to aesthetic value of landscape. Large area of paddy rice fields coupled with shallow ponded water provides a suitable habitat for many creatures and contributes to biodiversity conservation (Yoon, 2009). In this study cultural service of rice fields were quantified using indicators such as aesthetic value, recreational uses, number of education excursions and tourists to the rice fields, spiritual/religious value of the rice fields to the community.

2.7 Nitrogen and phosphorus retention in wetlands

Nitrogen is present in water in both inorganic and organic forms. The inorganic forms include ammonium, nitrate and nitrite while, organic form relates to decaying plant and animal matter. The sources of these forms of N in wetlands are surface run-off, groundwater inflow, wet and dry precipitation (Jansson *et al.*, 1998). On the other hand nitrogen is transformed and removed in a wetland through mineralization (ammonification), nitrification, assimilation (plant and bacterial uptake), nitrogen (N_2) fixation and denitrification (Saunders and Kalff, 2001; Verhoeven *et al.*, 2006; Hefting *et al.*, 2013) (Figure 1). However, the major removal mechanism for N in wetlands is nitrification and denitrification (Hefting *et al.*, 2013). Ammonium is oxidized to nitrate by nitrifying bacteria in aerobic zones of the wetlands of which the source of oxygen used is from the atmosphere and leakage from macrophytes roots. Nitrate is first reduced to nitrous oxide (N_2O) and then to nitrogen gas (N_2) which is emitted to the atmosphere from the wetland. Also ammonium and nitrate is taken up by plants and incorporated into biomass because they are bio-available/readily available (Figure 1). Nevertheless, ammonium and nitrate storage is temporary and only effective if the vegetation is harvested and removed prior to die-off before both nutrients are released back into the wetland (Kanyiginya *et al.*, 2010).

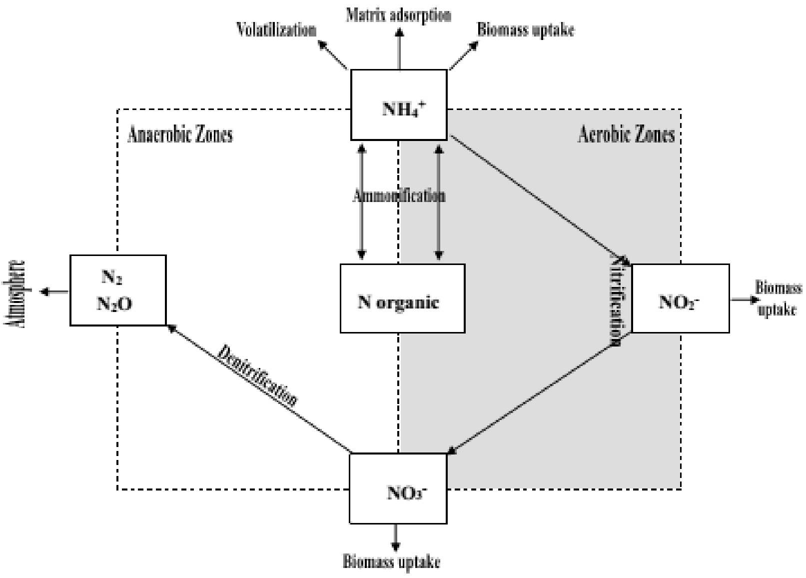


Figure 1: Nitrogen transformation and removal mechanism in wetlands (adapted from Cooper (1999))

Phosphorus (P) transformation and retention are key biogeochemical functions of wetlands that are important in improving water quality of both surface and subsurface waters. Unlike nitrogen, P cannot be eliminated from the wetlands by transformation into volatile substances equivalent to denitrification for nitrogen (Verhoeven *et al.*, 2006). The mechanisms of removal of phosphorus in through-flowing water in the wetland are by plant uptake, sedimentation, soil adsorption, microbial immobilization and precipitation. Accumulation of organic peat which is buried within the wetland as well as the outflows (surface and subsurface) from the wetland also removes P. Insoluble form of phosphorus is primarily removed under aerobic conditions by adsorption into soil while, soluble phosphorus is taken up by plants and bacteria and incorporated into biomass or adsorbed to wetland soil

(Badhe *et al.*, 2014). However, the soil chemistry is important if adsorption is the main removal mechanism of P in wetland. P adsorption is more pronounced if the soil contains aluminium compared to iron (Hogan *et al.*, 2004; Kelderman *et al.*, 2007). Furthermore, the adsorbed form of insoluble P in wetland sediments is also released back into the water through desorption influenced by bioturbation, sediment re-suspension and low oxygen level.

2.8 Total suspended solids removal in wetlands

Total Suspended Solids (TSS) are removed in the wetland through filtration and sedimentation (Arp and Cooper, 2004). Wetland vegetation provides hydraulic resistance and thus promotes sedimentation. Through this process a significant amount of other pollutants; nutrients, pathogens and organic matter are also removed and hence the net result is improved water quality.

2.9 Water purification in rice fields

Nitrogen and phosphorus are essential nutrients for the growth of rice and its yield (Kyaw *et al.*, 2005). However, N and P pose concern due to their contribution towards increasing eutrophication of water bodies (Kim *et al.*, 2006). Unlike most agricultural systems, principally managed for provisioning services, mainly food, rice fields can offer some unintended regulatory services especially water purification because of their capability to function as an artificial wetlands (MEA, 2005; Matsuno *et al.*, 2006; Zhang *et al.*, 2007; Yoon, 2009). The main inputs of N and P into paddy rice fields include irrigation water, fertilizer application, biological N fixation and precipitation (Kyaw *et al.*, 2005). Since rice is grown in ponded water, nutrients available in the water are either taken up by the rice plant or lost through nitrification, soil adsorption or denitrification (Matsuno *et al.*, 2006; Yoon, 2009; Onishi *et al.*, 2012). Forés and Comín (1992) states that bio-uptake is the major removal mechanism of nutrients of which rice plant removes 70% and 91% of total nitrogen and phosphorus. The submerged soils in ponded water are classified into upper aerobic and lower anaerobic zones of which the lower allow transformation and loss of NO_3-N through nitrification and denitrification. Phosphorus on the other hand is readily adsorbed in the soil coupled with desorption due to anaerobic conditions desorption of the soils.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Study area

3.1.1 Description of the study area

Nyando floodplain is located on the lowlands of Nyando River Basin; one of the sub-catchments of the Lake Victoria Basin in Kenya which covers an area of 3,600 km^2 and situated between longitudes 34º 47' 00" E and 35º 44' 00" E, and latitudes 0 º07' 00" N and 0º 20' 00"S (Swallow *et al.,* 2009; Raburu *et al.,* 2012a). The floodplain is dominated by Kano plains which cover approximately two thirds of the lower half of River Nyando Basin (Raburu *et al.,* 2012a). The Kano Plains is a lowland flat area which extends from Miwani, Nyando, Lower Nyakach and Kisumu East sub-County. The topography of the plain varies with highest point (altitude of 1,801m above the sea level) in Muhoroni and lowest point having the same altitude as Lake Victoria at 1,134m above the sea level (Raburu *et al.*, 2012b).

Nyando floodplain is frequently inundated by floods as a result of River Nyando overtopping its banks. The river originates from the Mau Forest Complex situated on the eastern part of the Kenyan Rift Valley (MWENR, 2012; Raburu *et al.,* 2012b). It passes through the Kano plains before draining into Lake Victoria. The flooding in the plains is an annual evident attributed to the high discharge of the river in April and May as a result of accumulation of run-off in the upper reaches coupled with the alluvial soil that has poor drainage. River Nyando is also laterally confined in the southern end of the Kano plains at Ahero. In addition, the Kano plains are surrounded by steep hills such as Tinderet Hills to the East and Nandi Escarpment to the North (MWENR, 2012).

3.1.2 Climate of the study area

Generally, Nyando River Basin experiences a bimodal rainfall pattern with long rains in March-May and short rains in September-November (Khisa *et al.*, 2013). Rainfall in the basin ranges from 1,100 to 1,600mm annually with a minimum monthly rainfall of 72mm and maximum of 243mm. In comparison to upper reaches of the basin, the lower basin of which Nyando floodplain is part of, receives lower rainfall amount ranging from 600-1100mm annually. However, April and May are wettest months and contributes to 25% of the rainfall annually in the Nyando floodplain (MWENR, 2012).

Nyando floodplain experiences a sub-humid to semi-arid climate. The relative humidity fluctuates between 55% and 75% in the dry and rainy seasons respectively with high humidity in May and July and low in January and October. Temperature on the other hand, ranges from a minimum of 14ºC to 18ºC in August and September. The highest mean temperatures are recorded in June and July which ranges from 27ºC to 32ºC annually.

3.1.3 Land use activities in Nyando floodplain

The major land use activities generally in Nyando River Basin consist of indigenous and plantation forests, agriculture and shrub land. Agricultural activities such as large scale sugarcane farming, rice production , fishing as well as cattle keeping is common (Kipkemboi *et al.*, 2006; Raburu *et al.*, 2012b). However, the "black cotton" soil which is characterized by poor drainage system coupled with the warm climate as well as relatively low rainfall and periodic flooding and drought make farming in most parts of the floodplain unattractive as an economic venture.

3.1.4 Study sites

This study was conducted in three sites within Nyando floodplain in Ombeyi location. The location is situated between latitudes 00º 10' 00" S and 00º 07' 00" S, and longitudes 34º 58' 00" E and 34º 54' 00" E in western part of Kenya, Nyando sub-County. The sites include; Ombeyi natural wetland, Kore Irrigation Scheme and Ahero Irrigation Scheme.

Ombeyi natural wetland is a small swamp which covers an area of approximately 176 acres (Figure 2). It is located between latitudes 00º 08' 00" S and 00º 07' 00" S, and longitudes 34º 57' 00" E and 34º 56' 00" E. It is adjacent to the Kore Irrigation Scheme which is fed by River Ombeyi that drains through heavily populated Bwanda and Kobura plains and ends into Lake Victoria shore wetlands. River Ombeyi on the other hand is fed by Oroba and Nyakoko streams which in turn derive their waters from the upper Nandi escarpment (MWENR, 2012).

The wetland vegetation is dominated by *Cyperus papyrus*. Other macrophytes found in the wetland are *Phragmites australis, Cyperus imensis* and *Typha domingensis* among others. The wetland is also inhabited by birds, reptiles, amphibians and fish.

Kore Irrigation Scheme is the largest farmers managed irrigation scheme in Nyando floodplain started in 1991 through farmers' own initiative. The scheme is located between latitudes 00º 08' 00" S and 00º 07' 00" S, and longitudes 34º 57' 00" E and 34º 55' 00" E. It lies adjacent to the Ombeyi natural wetland (Figure 2). The area covered by the scheme is 2,340 acres with approximately 700 farmers (pers. comm. with Joseph Kenye (Chairman of Kore Irrigation Scheme). However, the size of the scheme is likely to increase with time due to continuous conversions of Ombeyi natural wetland into rice fields (personal observation).

The Kore Irrigation Scheme has three "blocks"; Kore 1A, Kore 1B, and Kore II. However, the sizes of the three "blocks" are unknown due lack of delineation. Rice varieties grown in the scheme are IR 2793 and Basmati 370 with rice yield of 5.5 tonnes ha^{-1} (Ong and Orego, 2002). The irrigation scheme practises less intensive farming whereby only farmers who can afford fertilizers do apply it in their farms. The source of water for irrigation is River Ombeyi which is partly diverted via a canal into the irrigation scheme. The drainage and irrigation canals are poorly designed and maintained with most rice fields getting water either from adjacent rice plots or from the drainage canals. This poor setup makes it difficult to establish the water purification service provided by the rice fields at the scheme.

Unlike Kore, in Ahero Irrigation Scheme, irrigation and drainage canals are well constructed, maintained and organised. Due to this, Ahero scheme was chosen to study water purification ES function in rice fields. The scheme is situated between latitudes 00º 09' 14.31" S and 00º 08' 00" S, and longitudes 34º 59' 49.16" E and 34º 55' 00" E. It was established through conversion of parts of the palustrine (swamps) Nyando wetlands into rice fields' (Ong and Orego, 2002; Swallow *et al.*, 2007) for rice production by the National Irrigation Board (NIB) in 1966 and became operational in 1969 (NIB, 2014). On inception, the scheme covered an area of 890 ha but currently (2014) the area under irrigation has increased to approximately 1740 ha with 519 farmers possessing farm size ranging from 1-4 acres (NIB, 2014). The irrigation scheme's source of water is River Nyando and River Ombeyi (locally known as River Miriu). Both rivers flow past the periphery of the Ahero Irrigation Scheme (Figure 2) from which the water is pumped and then conveyed by gravity through intake gates, feeder canals and into the rice fields via small inlets. The scheme practises intensive rice farming which includes application of fertilizers. Rice varieties grown in the scheme include; IR 2793, Basmati 370, BW 196 and ITA 310 with a yield of 3.5-4.5 tonnes per ha and net income KES 25,000-35,000 per planting season being registered (NIB, 2014).

This scheme consists of 12 main irrigation blocks (A-P minus E, I, H and J) ranging from 0.31-1.15 km^2 (NIB, 2014). Drainage water from the rice fields in majority of the blocks is channelized to drain into River Nyando and River Ombeyi. In other blocks drainage water is channelled into another farmers managed rice irrigation scheme known as Siso. This study was carried out in block G within three randomly selected rice plots each having a size of approximately 1 acre. The block had been chosen because the current (December 2014) rice transplant period coincided with the inception of this study and also by the fact that the rice fields drain into River Ombeyi.

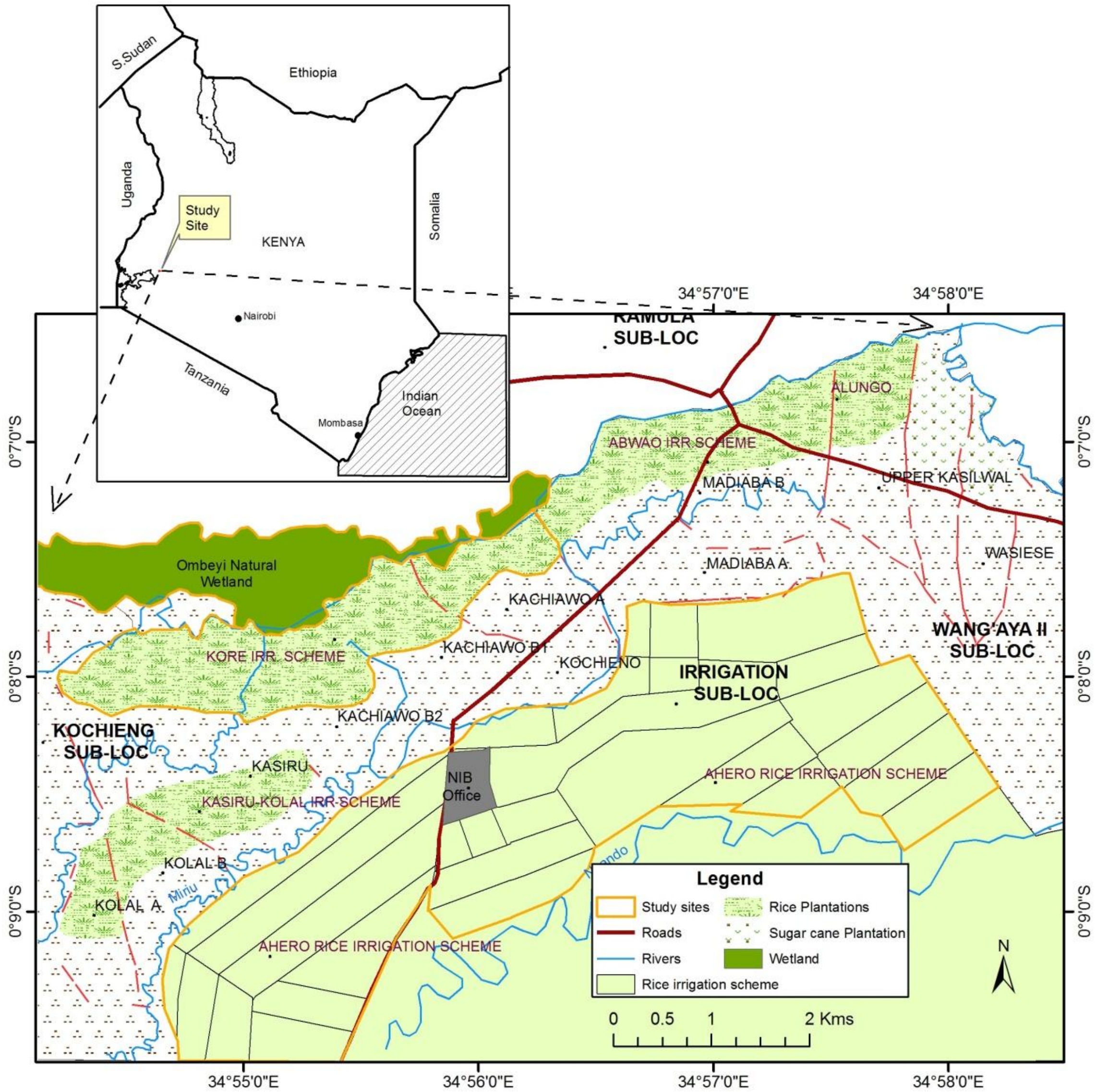


Figure 2: Map showing Ombeyi natural wetland, Kore Irrigation Scheme and Ahero Irrigation Scheme. (Source: Co-management of wetlands ecosystems and irrigation in Lake Victoria basin project report (Courtesy of Serena Nasongo)).

3.2 Study design

This study was conducted for a period of four months running from December 2014 to March 2015. It involved use of questionnaire survey targeting 151 farmers and one focus group discussion (FGD) consisting of 12 persons from the community managed Kore Irrigation Scheme. The sample size used in the questionnaire survey was according to Israel (1992) formula for determination of sample size with a precision level of ±10% and confidence interval of 95%. The questionnaire survey was used to evaluate the provisioning and cultural ES provided by both Ombeyi natural wetland and rice fields in Kore Irrigation Scheme. The purpose of the FGD was to assess and validate the responses given by the farmers on the ES provided by the rice fields and the natural wetland. Indicators of measurements for each ES such as rice and fish production for provisioning services and aesthetic value for cultural services among others as illustrated in table 1 were identified based on the farmers' response on ES derived from both Ombeyi natural wetland and rice fields. For the assessment of water purification ES function of the natural wetlands and rice fields, water samples were collected in both Ombeyi natural wetland and Ahero Irrigation Scheme's rice fields at various sampling points as shown in figure 3 and 4 and analysed for changes in nutrients and physico-chemical variables.

3.2.1 Questionnaire Survey and Focus Group Discussion (FGD)

Purposive sampling (sampling based on background knowledge about the population) was conducted to select 151 farmers owning farms in Kore Irrigation Scheme who were used to gather information in the survey. Semi-structured questionnaire survey was administered to the respondents face to face. The questionnaires were first pre-tested on 10 farmers after which they were adjusted to ease interpretation by enumerators and make the questions more understandable to the respondents. During the interviews, two sets of questionnaires were used. One set was first administered to 60 randomly selected farmers in order to assess the ES which were generally derived from both Ombeyi natural wetland and the rice fields (see appendix 1 and 2). The responses obtained from the farmers on various ES in both systems were later used to identify and develop indicators of ES measurements as shown in table 1. The indicators were in turn used to develop the second set of questionnaires (see appendix 3 and 4) in both Ombeyi natural wetland and rice fields which were administered to 91 farmers.

The data collected in terms of provisioning services included papyrus mat making, rice production, fish production, reeds utilization and wild game meat provision using various indicators of measurements as illustrated in table 1. The average number and price of bundles required for provisioning services such as mat making and those from reeds utilization were calculated based on the farmers' responses. Also, the average price of the variety of fish; lung fish, catfish and Nile tilapia harvested from both the rice fields and natural wetland were calculated based on the data collected from the farmers. Cultural ES investigated in Ombeyi natural wetland and rice fields in Kore Irrigation Scheme included religious/spiritual, aesthetic value, educational activities/excursions, ecotourism and recreational uses. A Likert scale used by the respondents to grade the ES derived from both systems was 1-5 (4-5=high, 2-3=medium and 0-1=low). Questionnaire survey was followed by the formation of one FGD consisting of 12 local inhabitants; four village elders, four rice fields' block leaders and four farmers whose household depended directly on wetland products.

Table 1: Indicators for ecosystem goods and services provided by natural wetland and rice fields (Modified from (Swallow *et al.*, 2009; Posthumus *et al.*, 2010)

Ecosystem goods and services	**Indicator**	**Unit of measurements**
Rice production	Rice yield	Kg/acre/year
	Area under production	acres
	Price of rice per bag	KES
Fish provision (Lung fish, catfish and Nile tilapia)	Price of fish per piece	KES
	Number of fish	No. per year
	Gross income	KES/year/farmer
Wild game meat provision	Wild game availability	Likert scale; score (Low, high and medium)
Thatching grass (*Cyperus imensis*)	Price of a bundle of grass for building	KES
Reeds (*Phragmites australis*)	Price of a bundle of reeds for building houses, toilets and bathrooms, fencing	KES
	Price of a bundle of reeds for firewood	KES
Papyrus (*Cyperus papyrus*) for mat making	Price per unit of mat	KES
	Price/mat/year	KES
Water purification	Nutrient retention	Percentage (%)
	Sediment retention	Percentage (%)
Recreation	Recreational use	Likert scale; score (Low, high and medium)
Aesthetic value	Aesthetic value	Likert scale; score (Low, high and medium)
Tourism	Frequency of tourists per year	Likert scale; score (Low, high and medium)
Educational excursions	Number of educational excursions per year	Likert scale; score (Low, high and medium)
Religious/spiritual uses	Religious/spiritual use	Likert scale; score (Low, high and medium)

3.2.2 Field measurements and water samples collection

Physico-chemical parameters; dissolved oxygen (DO), pH, water temperature and electrical conductivity (EC) were measured *in-situ* at various sampling points in Ombeyi natural wetland, Ahero Irrigation Scheme and River Ombeyi (Figure 3 and 4) for a period of 4 months (December 2014-March 2015) using a calibrated HQ 40d (HACH) multi-meter. During the sampling period, water samples for nutrients (SRP, TP, NO_3-N, NO_2-N, NH_4-N and TN) and TSS analysis were collected from Ombeyi natural wetland in duplicates using 500 ml acid-washed plastic bottles, River Ombeyi and three randomly selected rice fields in Ahero Irrigation Scheme. The four months sampling period was chosen since it was the duration required for rice grown in the selected rice plots to mature and water drained from rice fields to allow for harvesting.

Water samples were collected in River Ombeyi (RO) to determine the actual concentration of nutrients and sediments in the river before it was diverted into Kore Irrigation Scheme and the adjacent Ombeyi natural wetland (Figure 3). In Ombeyi natural wetland, water samples were collected at the inlet of the wetland (WI) and outlet of wetland (WO) as shown in figure 3. In Ahero Irrigation Scheme, samples were collected at the inlet and outlets of each of the three identified rice plots and also at the drainage canal (S7) (Figure 4). Water samples for the rice fields' inlets (S1-S3) were collected during irrigation while those of the outlets (S4-S6) were collected near the outlet of the rice plots to represent the outlet since there were continuous seepages of water from the rice fields as a result of poor sealing of the outlet. However, when rice was mature and almost ready for harvesting, the paddies were fully drained and water samples collected at the open outlets. Sampling of the drainage canal was important in determining the actual concentration of nutrients and sediments flowing into River Ombeyi, as an indicator of water purification function of the rice fields. For quality control, the water samples collected from various sites in the natural wetland, rice fields and River Ombeyi, were stored in a cool box and transported to the water quality laboratory at Egerton University for analysis immediately on arrival.

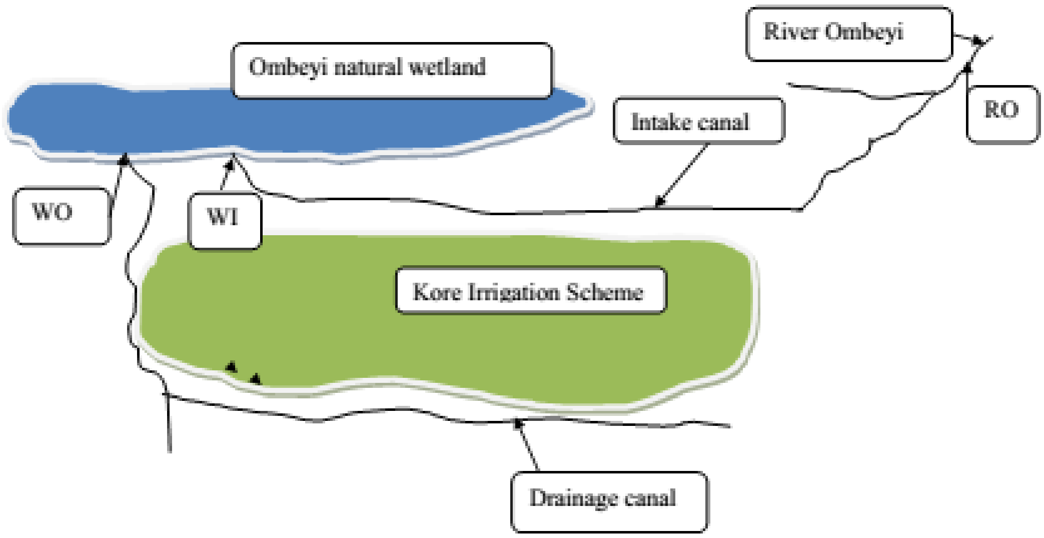


Figure 3: Sampling layout for Ombeyi natural wetland in relation to Kore Irrigation Scheme (Source: Self developed).

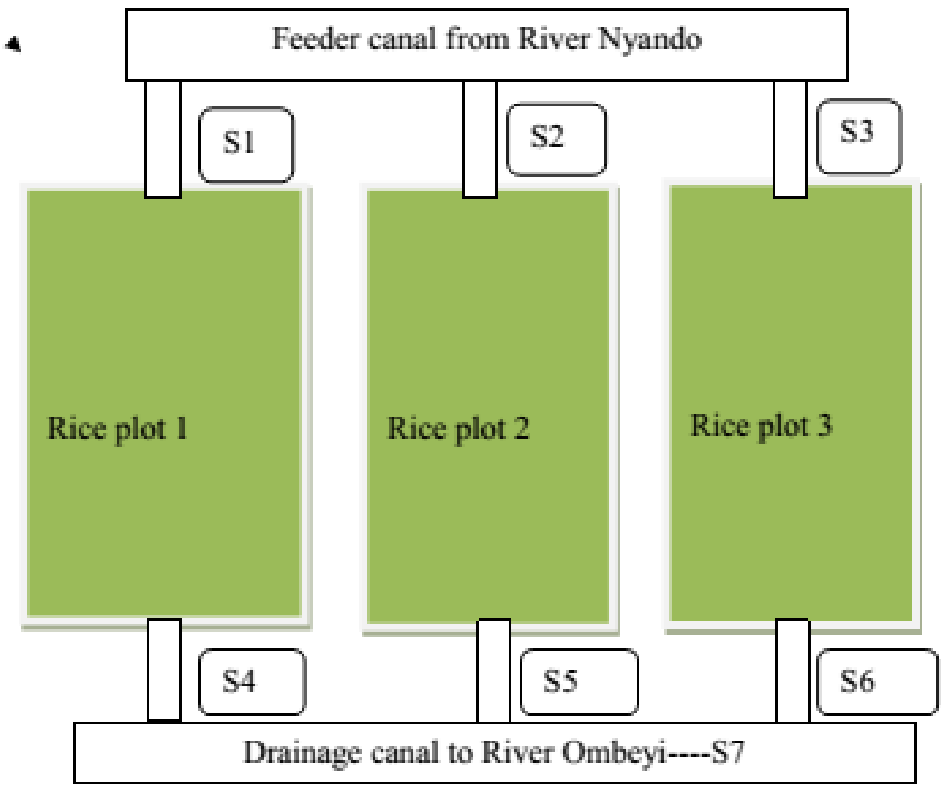


Figure 4: Layout of selected rice plots and sampling points (S1 to S7) within Ahero Irrigation Scheme (Source: Self developed).

3.2.3 Plant samples collection

The above ground biomass of macrophytes in Ombeyi natural wetland and rice plants from Ahero Irrigation Scheme were determined by harvest method (Kanyiginya *et al.*, 2010). Wetland macrophytes; *Cyperus papyrus* and *Phragmites australis* and rice plants were harvested to determine biomass and nutrients uptake by respective plants. Plant for biomass samples were harvested in 0.5×0.5m randomly selected quadrats by cutting above the ground level. In Ahero Irrigation Scheme, smaller quadrats measuring 0.2m ×0.2m were used for rice harvesting to address the concern of the farmers on the amount of crop harvested within the rice plots. Two harvestings for rice biomass were done, the first harvesting was conducted eight weeks after transplanting, whereas the second harvesting was done sixteen weeks after rice transplanting when rice was mature and ready for harvesting.

3.2.4 Determination of nitrogen and phosphorus in water samples

Different forms of nitrogen were determined; Ammonium-Nitrogen (NH_4-N), Nitrate-Nitrogen (NO_3-N), Nitrite-Nitrogen (NO_2-N) and Total Nitrogen (TN) using standard methods according to APHA (2004) method. The NH_4-N was determined by sodium-salicylate method, where 2.5ml of sodium-salicylate solution and 2.5 ml of hypochloride solution were added to 25 ml of filtered water samples from the natural wetland, River Ombeyi and rice fields. The samples were incubated in the dark for 90 minutes after which the absorbance read at a wavelength of 665nm using a GENESYS 10uv scanning spectrophotometer. NO_3-N was determined using sodium-salicylate method, where 1 ml of freshly prepared sodium salicylate solution was added to 20 ml of filtered water sample. The processed samples were then placed in the oven and evaporated to complete dryness at 95ºC. The resulting residue was dissolved using 1ml H_2SO_4, followed by addition of 40ml of distilled water and 7ml potassium-sodium hydroxide-tartrate solution respectively and read at a wavelength of 420 nm. NO_2-N was analyzed through the reaction between sulfanilamid and N-Naphthyl-(1) ethylendiamin-dihydrochlorid and absorbance read at a wavelength of 543nm.

Total nitrogen (TN) was determined through persulphate digestion in which 1 ml of warm potassium persulphate was added to 25 ml of unfiltered water sample to convert the nitrogen forms into ammonium. The samples were autoclaved for 90 minutes at 120ºC and 1.2atm. After digestion, the total reduced forms into ammonium were analysed using sodium-salicylate method. The final concentrations of NH_4-N, NO_3-N, NO_2-N and TN were calculated from their respective equations generated from standard calibration curves (APHA, 2004).

Soluble reactive phosphorus (SRP) was analyzed using the ascorbic acid method (APHA, 2004). The prepared reagents of ammonium molybdate solution (A), sulphuric acid (B), ascorbic acid (C) and potassium antimonyltartrate solution (D) were mixed in a ratio of A:B:C:D= 2:5:2:1 (ml). The resulting mixed solution were added to the filtered water sample at a ratio of 1:10 and the absorbance read at 885nm wavelength using a GENESYS 10uv scanning spectrophotometer after 15 minutes of reaction and concentration determined from known concentrations of standard solutions (APHA 2004). Total phosphorus (TP) was determined through persulphate digestion of unfiltered water to reduce the forms of phosphorus present into SRP. After the digestion, evaporated water was replaced and TP analyzed as SRP using ascorbic acid method. The concentration of TP was determined from similarly processing of known concentrations of phosphorus standard solutions (APHA 2004).

3.2.5 Total Suspended Solids (TSS)

Total Suspended Solids (TSS) was estimated gravimetrically by filtering a known volume of water samples through pre-weighed Whatman GF/C filters of pore size 0.45µm. The filter papers were then dried to a constant weight at 95ºC for 3 hours. The TSS weight were calculated using modified APHA (2004) formula;

$$\mathrm{TSS} = \left((\mathrm{Wc} - \mathrm{Wf})\mathrm{x}\ 10^{6}\right)\mathrm{V}^{-1} \qquad \text{(I)}$$

Where TSS = Total suspended solids (mg L^{-1}), Wf = Weight of dried filter paper in grams, Wc = Constant weight of filter paper + residue in grams and V=Volume of water filtered (ml)

3.2.6 Hydrological measurements

The water discharge flowing into and out of the Ombeyi natural wetland and rice fields' drainage canal was determined using Velocity-Area method. A portable automatic flow meter (Flo-Mate, model 2000, Marsh McBirney) was used to measure the mean water velocity at 60% water depth across the channels and discharge calculated according to Wetzel (2001) formula;

$$Q = \Sigma \mathrm{yiAi} \qquad \text{(II)}$$

Where Q = discharge, y_i = mean current velocity (m/s) and A_i = channels cross sectional area (m^2).

3.2.7 Loading rates

Nutrient and sediment loadings or losses in both Ombeyi natural wetlands and drainage canal were calculated according to Kitaka (2000) as follows;

$$\text{Nutrient loading/loss} = \text{Discharge} * \text{nutrient concentration} * 0.0864 \qquad \text{(III)}$$

$$\text{Sediment loading/loss} = \text{Discharge} * \text{sediment concentration} * 0.0864 \ldots\ldots\ldots\ldots \text{(IV)}$$

Where nutrient loading/loss (kg/day), discharge (L/S), nutrients/sediment concentration (mg/L) and 0.0864 is concentration time conversion factor from $mgs^{-1}$to kgd^{-1}.

3.2.8 Determination of above ground biomass of plants and nutrient analysis

The biomass was determined as dry weight of the harvested plants from the quadrats. This was established by oven drying of the materials at 70ºC to a constant weight and the biomass expressed as dry weight per m^2.

Nutrient concentration in plants materials collected was determined by analyzing TN and TP from known weight of dried and grinded plants' samples. Total nitrogen was determined by digesting 0.3g of the dried ground plants' samples (<0.25mm,60 mesh) using 3.2 g of salicylic acid dissolved in 100ml of sulphuric acid-selenium mixture (Okalebo *et al.*, 2002). Sampled digestion was done using digestion block at a temperature of 110^{o}C for 1 hour and then 330^{o}C for 2 hours. The sample was cooled after digestion and diluted with distilled water. The diluted sample of 25ml was mixed with 40% NaOH and distillation done using boric acid. Finally, 150 ml of the distillate was titrated with 0.1M HCL. The nitrogen concentration in plant material was estimated according to Okalebo *et al.* (2002) as follows;

$$N\% = \frac{(Ts - Tb) * molarity\ of\ HCL * Eq.\ wt\ of\ N * DF * 100}{w\ *\ 1000} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(V)}$$

Where Ts = titre of the sample, Tb = titre of the blank, Eq. wt of N = 14.007 mg, DF = Dilution factor and w = weight of dried sample.

The obtained N% was further used to calculate the N accumulation per square metre in respect to the dry biomass.

$$\text{N}(\text{gm}^{-2}) = \text{N}\% * \text{plants biomass}\ (\text{gm}^{-2}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(VI)}$$

Total phosphorus (TP) was analyzed using ascorbic acid method (Okalebo *et al.*, 2002). Clear digested supernatant of 5ml was added to 20 ml of distilled water and 10 ml of ascorbic acid respectively and topped up with distilled water to a volume of 50ml. The sample was then mixed and left to settle for 1 hour to full colour development and absorbance read at 880nm. The concentration of TP in the digest was calculated from equation generated from standard calibration curve. The final TP concentration in the plant samples was expressed in % as follows;

$$\text{TP}\ (\%) = \frac{\text{c} * \text{v} * \text{f}}{\text{w}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(VII)}$$

Where c = concentration of P in the digest, v = volume of digest, f = dilution factor and w = weight of the sample (0.3g)

The obtained P% was further used to calculate the P accumulation per square metre in respect to the dry biomass.

$$\mathrm{P(gm^{-2}) = P\% * plants\ biomass\ (gm^{-2})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(VIII)}$$

3.2.9 Estimation of nutrients and sediments retention in Ombeyi natural wetland and rice fields

In Ombeyi natural wetland and rice fields, nutrients and TSS retention were calculated based on comparison of mean loading/concentration at the inlet with loss at the outlet of the systems. Sediments and nutrients loadings into R. Ombeyi from the rice fields' drainage canal were also determined. The TSS retention in the rice fields was calculated based on comparison of mean concentration at the inlets to the outlets. Therefore, nutrient and sediment retention in both Ombeyi natural wetland and rice fields was calculated according to modified Kanyiginya *et al.* (2010) formulae below;

1. Nutrient retention was calculated as;

$$\text{Nutrient retention (\%)} = \frac{\text{Inlet concentration} - \text{Outlet concentration}}{\text{Inlet concentration}} * 100 \ldots\ldots\ldots \text{(IX)}$$

2. Sediment retention was calculated as;

$$\text{TSS(\%)} = \frac{\text{Inlet concentration} - \text{Outlet concentration}}{\text{Inlet concentration}} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots.. \text{(X)}$$

3.3 Data management and analysis

Data collected was stored in Microsoft Office excel 2007 and statistically analyzed using IBM SPSS statistics 21 (USA). All tests were carried out at $p<0.05$ significance level and data subjected to a normality and homogeneity of variance tests. Normality distribution of data was checked by Shapiro-Wilk test while homogeneity of variance by Levene's test. The data for *in situ* measurements were normally distributed while TSS, TP, SRP and NH_4-N were not normally distributed. Standardization of the values and log transformation was used on variable prior to conducting parametric tests. Indicators of measurements of various provisioning ES such as fish and rice production in both Ombeyi natural wetland and rice fields were used to calculate average quantities and income generated from both systems in a year. For, cultural services frequency classification was used to grade the ES as high, low and medium. To determine nutrients and sediment retention in Ombeyi natural wetland and rice fields, descriptive statistical parameters such as mean and standard errors were calculated. Variations in mean concentration/loading or loss of nutrients; NO_3-N, NH_4-N, TN, SRP and TP in River Ombeyi, inlet and outlet of the natural wetland were compared using ANOVA. In rice fields ANOVA was also used to test variation in means at the inlet, outlet and drainage canal of rice fields. A Tukey's *post hoc* test was applied to separate means. Chi-square test was further used to compare nutrient and sediment retention in both Ombeyi natural wetland and rice fields in Ahero Irrigation Scheme and T-test to compare income generated from provisioning services in both systems.

CHAPTER FOUR
RESULTS

4.2 Provisioning ES in Ombeyi natural wetland

A total of 91 farmers representing Kore Irrigation Scheme gave their responses on the survey carried out on the provisioning ES derived from Ombeyi natural wetland. These ES included papyrus mat making, production of reeds for house roof thatching, fencing, building toilets and bathrooms, fishing baskets and firewood, grass (*Cyperus imensis*) for house roof thatching, fish and wild games used as food.

4.2.1 Papyrus mat making

Papyrus mat making materials was widely harvested from Ombeyi natural wetland with the majority, 93.4% (85) of the farmers being involved in commercial production of mats while the rest were not engaged on the activity. On average, one farmer was harvesting three bundles of dry papyrus thrice a week which was used to make an average of six mats per week. The mats were majorly for commercial purposes with each mat being sold at an average price of KES 76.60 (small mat) with a range of KES 50 to KES 150, whereas a medium sized mat were sold at KES 128.10 with a minimum of KES 50 and maximum of KES 180. Large mats on the hand were sold at an average price of KES 216.40 per unit with a maximum of KES 300 and a minimum of KES 100. Mat selling generated an average gross income between KES 460.90 to 1,298.80 depending on their sizes; KES 460.90 (small), KES 768.70 (medium) and KES 1,298.80 (large). The mats were made throughout the year hence, on average, 288 mats were produced annually by each farmer. This generated a yearly average gross income of KES 40,454.40 with a range of KES 22,124.20 to 62,343.40 per farmer.

4.2.2 Reeds and their indicators of measurements

Reeds were used by the community for various purposes; building (houses, toilets and bathrooms), fencing, firewood and making fishing baskets as shown in table 2. Most respondents, 90.1% (82), in Kore Irrigation Scheme reported use of reeds for various purposes while the rest did not use it. Among those who used it, 8.5% (7) used it for firewood, 68.3% (56) for building houses, 4.9% (4) for building toilets and bathrooms, 12.2% (10) for making fishing baskets and 6.1 % (5) for fencing.

Reeds harvested were tied into bundles which were used as their unit of measurement. However, the number and size of bundles varied from one use to another and also depended on the sizes of products generated for instance thatching a house, making fishing basket and constructing toilet among others as illustrated in table 2. The bundles for home fencing were sold at an average price of KES 74, roof thatching KES 88, firewood KES 67 and constructing toilets and bathrooms KES 43, whereas the price for fishing baskets made from reeds was KES 270 per basket.

Table 2: ES from reeds and their units of measurements

Use	Number of bundles required	Price per unit	Number of products generated
Home fencing	3	74	-
Roof thatching	11	88	1
Fishing baskets	2	270	3
Firewood	2	67	-
Building toilet and bathroom	2	43	1

4.2.3 House roof thatching as ES derived from wetland grass (*Cyperus imensis*)

Cyperus imensis locally known as *see* (Dholuo) was reported by respondents and later confirmed by FGD as currently scarce in Ombeyi natural wetland. Majority, 64.8% (59) of the respondents used it for house roof thatching whereas, only 35.2% (32) were not using it. The price of this per bundle ranged from KES 15 to 180 with a mean of KES 70 per bundle. Approximately 15 bundles were used to roof one house thus costing KES 1,050.

4.2.4 Fish derived from Ombeyi natural wetland

Fish harvesting as one of ES in Ombeyi natural wetland was reported to have declined over the past years. Some 58.2% (53) of respondents reported that fish were no longer found in the wetland while 41.8% (38) stated that fishing was still being conducted in the wetland and used for both commercial and subsistence purposes. The fish commonly harvested in the wetland included Nile tilapia (*Oreochromis niloticus*), lung fish (*Protopterus aethiopicus*) and catfish (*Clarias gariepinus*). Other fish species harvested here, though not quantified in this study included Longtail spiny eel (*Mastercembelus frenatus*) and Luambwa barb (*Barbus cercops*). For commercial use, the price varied on the basis of the fish type and the size. The price of lung fish ranged from KES 3 to 600, catfish KES 2 to 100 and tilapia KES 15 to 420 per fish. On average, weekly (referring to roughly 3 days in a week of wetland fishing) gross income generated per farmer from catfish was KES 432.20 with a range of KES 6 to 1,200. Lung fish generated an average weekly gross income of KES 932.90 with a range of KES 102 to 5,000 per farmer. Tilapia generated a weekly gross income of KES 795.80 with a range of KES 100 to 8,400. Therefore, the yearly gross income generated per farmer from catfish, lung fish and tilapia were KES 6, 915.80, KES 14,926.50 and 795.80 respectively. In summary, in a year, a mean gross income of KES 34,575.30 was generated per farmer from wetland fishing (Table 3).

Table 3: Fish species commonly harvested in the natural wetland and gross income generated from fishing

Scientific name	Common name	Gross income per week (KES)	Gross income per year (KES)
Clarias gariepinus	Catfish	432.20	6, 915.80
Protopterus aethiopicus	Lung fish	932.90	14,926.50
Oreochromis niloticus	Nile tilapia	795.80	12,732.90
Total gross income (KES)		2,160.90	34,575.20

4.2.5 Wild game meat as provisioning ES

The wild games commonly used as food in Ombeyi natural wetland included Sitatunga (*Tragelaphus spekei*), hippos (*Hippopotamus amphibious*), Bohor reedbuck (*Redunca redunca*), Scaly francolin (*Ptemistis squamatus*) and wild rabbits. Others were Saddle-billed stork (*Ephippiorhynchus senegalensis*), guinea fowl (*Numida meleagris*), otters (*Aonyx capensis*) and wild ducks. In Kore Irrigation Scheme, the wild games were used by 96.7% (88) of the respondents as food while 3.3% (3) stated otherwise. Based on Likert scale the community's perceptions on wild games population was graded as low for Sitatunga, Bohor reedbuck, hippos and Abur while wild rabbits and Scaly francolin were graded as high. Wild games such as wild ducks, otters, guinea fowl and Saddle-billed stork were only reported by 2 to 4 respondents out of 88 and therefore it was challenging to score their population. The low number of wild games in Ombeyi natural wetland was confirmed by FGD.

4.2.6 Status of Ombeyi wetland provisioning ES over the past 20 years

Current and past wetlands products availability were compared by the respondents in relation to their increase, decrease, no change or loss as perceived by the community members over the past 20 years. This time period was used since it is the period that has elapsed since the establishment of Kore Irrigation Scheme in 1991 from Ombeyi natural wetland.

Reduction in papyrus availability was widely reported by the respondents (62.6%) while only 3.3% (3) had no opinion on the matter. Increased availability was reported by 25.3%, whereas 8.8% stated no change (Figure 5a). Decrease in reeds availability was reported by 70.3% of the respondents, whereas 18.7%, 7.7% and 3.3% stated increased, no change and no opinion on reeds availability respectively (Figure 5b). Decrease in wetland grass on the other hand was reported by 78% of the respondents while increased availability by 6.6% of the respondents (Figure 5c).

Most respondents (85.7%) stated that over the last 20 years population of wild game has declined while 12.1% and 2.2% stated increased and lost respectively (Figure 5d). Similar observations were made on the decline of fish species and population by 65.9% of the respondents while 23.1% reported increased and only 5.5% (3) had no opinion on the matter (Figure 5e).

4.3 Provisioning ES from rice fields in Kore Rice Irrigation Scheme

4.3.1 Rice production

Rice farming was a key activity in Kore Irrigation Scheme as all respondents, 100% (91 farmers) reported that they grow rice. The size of farm possessed by each farmer ranged from 0.25acres to 8.25 acres with an average of 1.5 acres. Rice grown in the scheme was majorly for commercial purposes and the maximum number of bags an individual had obtained in the last rice growing season (January 2015) was 100 bags and a minimum of 2 bags. A mean production of 19 bags per 1.5 acre farm, with an average selling price per bag of KES 3,236.20 was generated par farmer. However, the selling price ranged from KES 2,500 to 4,500 depending on the quantity (kg) of the bag of rice, which ranged from 90 to 230 kg with a mean of 167kg. The fact that rice was grown mainly for commercial purpose once a year implies that on average, in a 1.5 acre farm, a farmer generated a mean gross income of KES 61,488.90 with a maximum of KES 323,626 and minimum of KES 6,472.50 per year. In comparison to yearly gross income generated from papyrus mat making per farmer, rice fields generated significantly higher income (T-test; $F=20.840$, $d.f=173$, $p=0.001$).

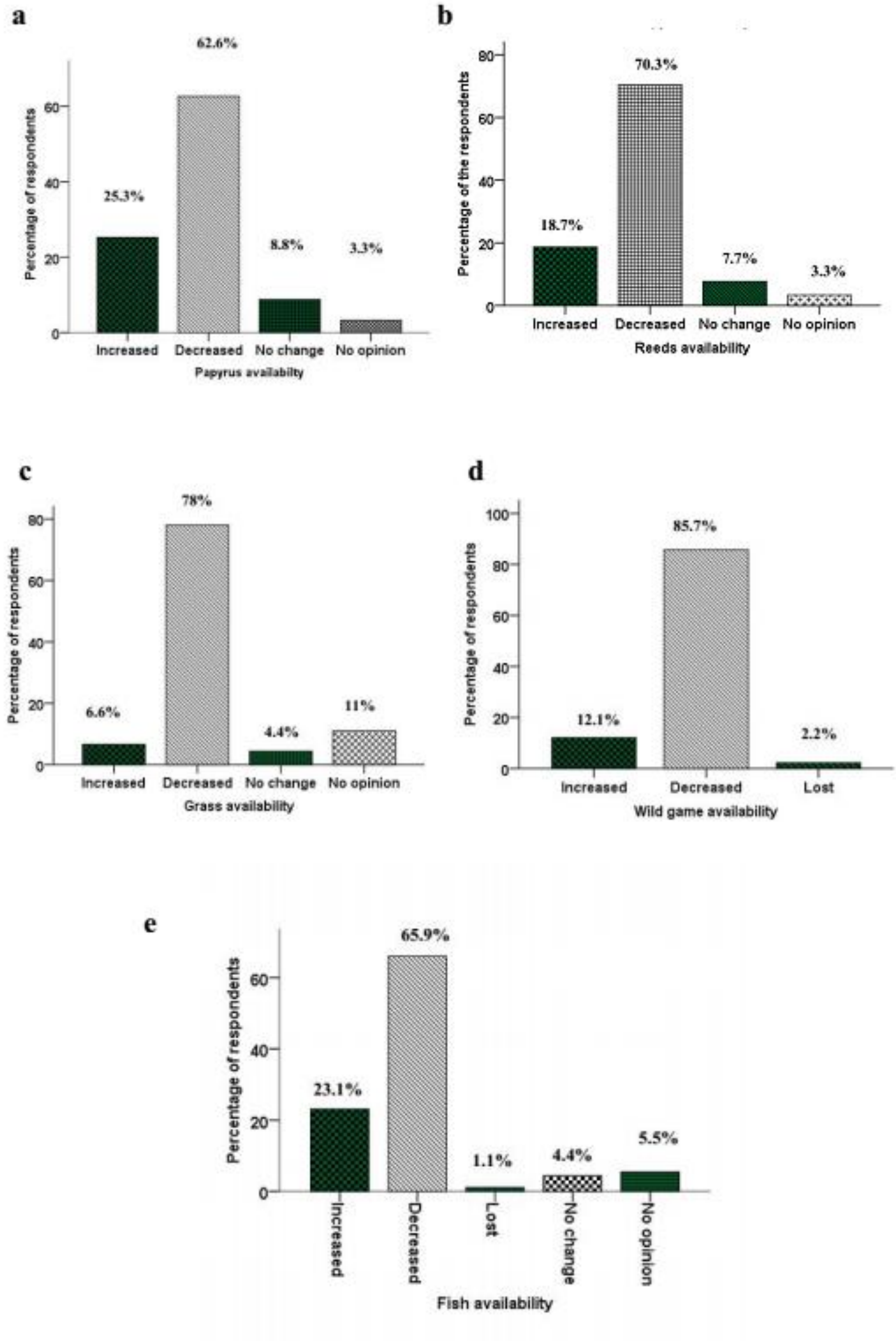


Figure 5: Community's perception on changes in Ombeyi natural wetland's products provision

4.3.2 Fish production from rice fields

Majority, 76.9% (70) of the respondents reported fishing of wild fish in the rice fields and irrigation canals while the rest stated otherwise. Fish species harvested were not different from the wetland species. The commonly harvested fish included Nile tilapia (*Oreochromis niloticus*), lung fish (*Protopterus aethiopicus*) and catfish (*Clarias gariepinus*). Other fish species harvested but not quantified in this study were Longtail spiny eel (*Mastacembelus fretanus*) and Luambwa barb (*Barbus cercops*). Fish was used for both commercial and subsistence purposes. For commercial purpose, the amount of money earned per farmer from catfish ranged from KES 2 to 80 with a mean of KES 10.20 per fish. An average gross income of KES 770.70 was generated by each farmer per week with a minimum of KES 20 and maximum of KES 5,000. For lung fish a minimum of KES 10 and maximum of KES 500 with a mean of 162.10 was generated per fish. The mean income from lung fish in a week per farmer was KES 1,786. Tilapia on the other hand was sold at a price ranging from KES 2 to KES 300 per fish (Table 4) with an average gross income generated per week by each farmer being KES 917.30 (maximum of KES 5,000 and minimum of KES 100). Nonetheless, fishing was only available in the paddy fields during the four month rice growing seasons (October to January) and closer to the natural wetland habitats in a year as revealed by FGD. The mean gross income generated per farmer from catfish was KES 12, 330.70 with a range of KES 320 to 80,000, whereas lung fish and tilapia generated a gross income of KES 28,576 and KES 14,676.30 per year respectively. Consequently, in a year, gross total income of KES 55, 583 was generated per farmer in the rice fields fishing. In comparison to natural wetland fisheries, there was no significant difference in the annual gross income generated per farmer from rice fields' fisheries (T-test; F=0.421, d.f=217, p=0.421).

Table 4: Fish species and gross income generated from fishing in rice fields in Kore Irrigation Scheme

Scientific name	**Common name**	**Gross income per week (KES)**	**Gross income per year (KES)**
Clarias gariepinus	Catfish	770.60	12,330.70
Protopterus aethiopicus	Lung fish	1,786	28,576
Oreochromis niloticus	Nile Tilapia	917.20	14,676.30
Total Gross Income (KES)		3,473.80	55, 583

4.4 Cultural ES in Ombeyi natural wetland and rice fields in Kore Irrigation Scheme

In the natural wetland, religious/ spiritual uses included water baptism, spiritual cleansing and cultural rituals such as driving evil spirits into the wetland. In addition, traditional healers directed their clients to bath in the wetland at dawn so as to be cleansed from certain diseases since the areas were perceived as cleansers (locally known as *Manyasi*). Religious/spiritual uses of the wetland by the local community were reported by majority of the respondents, that is, 59.3% (54) while 40.7% (37) of the respondents pointed out that such uses of the natural wetland by the community no longer existed. Some 51.9% (28) rated this practice as low whereas 38.9% (21) and 9.3% (5) scored medium and high respectively. Contrary to many respondents' views on religious/spiritual activities in the natural wetland, FGD indicated that the uses were medium based on the opinion that the activities were grounded in Luo culture and still being upheld.

In case of uses of the rice fields 64.8% (59) of respondents, 64.8% confirmed their value for religious/spiritual purposes. Only 35.2 % (32) of the respondents stated otherwise. The most common and probably the only one was the application of traditional medicine in the rice fields believed to prevent hailstones from destroying rice. According to 39% (23) of the respondents the religious uses of the rice fields were high, whereas 30.5 % (18) and another 30.5% (18) coincidentally ranked the uses as medium. This use was authenticated by FGD as the most common use in the rice fields.

The study revealed that 92.3% (84) of the respondents viewed natural wetland as playing significant aesthetic role because of their beauty. Some of the features which were considered to add beauty to the wetland included birds, variety of macrophytes and the micro-climate provided by the wetland. Contrarily, some 7.7% (7) of the respondents pointed out that the wetland was a "wasteland" and should be used entirely for rice farming. Moreover, they indicated that the landscape was familiar to them and the birds were considered as rice pests and destructive and thus reducing rice yield. Therefore, no aesthetic value was attached to the wetland by the respondents. In regards to scoring of aesthetic values of the wetland, 47.6% (40) of the respondents pointed out that the values were medium while 35.7% (30) and 16.7% (14) scored high and low respectively.

In the rice fields, aesthetic value was acknowledged by majority 95.6% (87) of the respondents but 4.4 % of the respondents viewed it as having no aesthetic value. Among the respondents who reported aesthetic value of the rice fields, 54% (47) indicated that such values were medium, while 18.4% (16) and 27.6% (24) ranked the service as high and medium respectively.

Ecotourism use of the wetland was reported by 85.7% (78) of the respondents and 14.3% (13) were of the contrary opinion. However, use of the wetland for ecotourism was rated as low since 64.1% (50) of the respondents stated that only a few tourists visited the area annually although some 23.1% (18) and 12.8% (10) rated them as medium and high respectively. According to FGD such uses of the wetland no longer existed since those features such as wild game and macrophytes that can attract tourists to the area too few or totally missing from Ombeyi wetland as a result of habitat destruction. Rice fields were viewed as valuable for ecotourism by 87.9% (80). Some 12.1% disagreed stating that the frequency of tourists coming to rice fields per year was low. Some respondents, 33.8% (27) and 20% (16) ranked them as medium and high respectively.

Majority, 84.6% (77) of the respondents acknowledged the use of the wetland for educational activities and excursions. Only 15.4% (14) of the respondents pointed out that there were no educational excursions or activities in the wetland. However, such uses per year were rated as low by more than half of the respondents (50.6% (39). Those respondents who considered such uses as medium followed closely at 42.9% (33) and only 6.5% (5) rating them as high. In the case of rice fields, most respondents (93.4% (85)) reported their use of the rice fields for educational purposes while only 6.6% (6) did not. Although most respondents agreed that the rice fields could be important education actual education visits were still low. Only 11.8% reported that such uses were high, 42.9% gave medium rating.

Recreational use of the wetland which was investigated was swimming. According to the respondents, 83.5% (76) of the community used the ponds and canals in the wetland and also the river passing in the wetland for swimming. The respondents who did not consider recreational uses of the wetland were 16.5 % (15). 25% (19) of the community rated recreational use of the wetland as low while 47.4% (36) and 27.6% (21) rated high and medium respectively. Nonetheless, FGD pointed out that such uses are negligible and hence were scored as very low which was contrary to majority of the respondents. This was attributed to drying out of the ponds which were used for swimming some years back.

In the rice fields, recreational uses such as swimming in the irrigation and drainage main canals were widely reported among the respondents (74.7%). However, 25.3% (21) indicated that the rice fields did not offer such services. Among the respondents that reported recreational uses of the rice field, 54.4% (37) score high while 25% (17) and 20.6 %(14) ranked them as medium and low respectively.

4.5 Water purification ES in Ombeyi natural wetland

4.5.1 Spatial variation of physico-chemical parameters in Ombeyi natural wetland

(a) Variation of *in situ* measurements in River Ombeyi, inlet and outlet of the wetland

The mean values and ranges for DO, water temperature, pH and EC at the inlet and outlet of Ombeyi natural wetland and River Ombeyi are presented in table 5 below. The mean DO concentration declined from River Ombeyi to the outlet of the natural wetland. It was observed that there was no significant difference in the concentration among sites (ANOVA; F=0.13, d.f=21, p=0.987). Electrical conductivity increased from the river to the outlet of the wetland. The mean EC at the outlet was highest compared to the inlet of the wetland and the river. At the inlet the EC was 112.5±4.6µS/cm with a maximum value of 136.7µS/cm and a minimum 98.8µS/cm. At the outlet, mean EC of 113.4±5.4 µS/cm was recorded with a range of 97.7µS/cm to 142.4µS/cm, whereas in the river EC of 110.8±4.1µS/cm with a range of 98.6µS/cm to 122.9µS/cm were observed. The EC did not vary significantly among the sites (ANOVA; F=0.068, d.f=21, p=0.934). The mean water temperature increased from the river to the outlet of the wetland. Nonetheless, it did not vary significantly among the sites (ANOVA; F=0.870, d.f=21, p=0.435).The pH ranged from 6.9 to 8.3 at the inlet of the wetland, 6.9 to 7.9 at the outlet of the wetland and 6.8 to 8.1 in the river.

Table 5: Mean values and ranges of physico-chemical variables in River Ombeyi, inlet and outlet of the wetland. ± represents standard error of the mean and the values in parenthesis are the ranges (n=22).

Physico-chemical variables	**River**	**Inlet**	**Outlet**
DO (mg/l)	4.0±0.1	3.9±0.3	3.7±0.3
	(3.7-4.2)	(2.9-4.9)	(2.8-4.9)
Temp℃	22.0±1.1	23.7±1.1	24.0±1.1
	(19.2-26.6)	(20.9-29.3)	20.6-29.8
pH	(6.8-8.1)	(6.9-8.3)	(6.9-7.8)
EC (µS/cm)	110.8±4.1	112.5±4.6	113.4±5.4
	(98.6-122.9)	(98.8-136.7)	(97.7-142.4)

(b) Variation in ammonium-nitrogen, nitrate-nitrogen and total nitrogen concentration in River Ombeyi, inlet and outlet of the wetland

Results for spatial variation in NH_4-N, NO_3-N and TN at the inlet and outlet of the wetland during the study period of December 2014 to March 2015 are presented in figure 6 below. Ammonium-nitrogen (NH_4-N) concentration was lowest (0.02±0.01mg/l) in the river while the highest concentration was observed at the inlet of the wetland (0.04±0.01mg/l). No significant difference was observed among the sites (ANOVA; F=1.094, d.f=21, p=0.355). Mean nitrate concentration was 40± 23.7mg/l and 52.8±17.9 mg/l in the river and outlet of the wetland respectively. Nonetheless, there was no significant difference in the mean concentration of nitrate among the sites (ANOVA; F=0.141, d.f=21, p=0.870). Total nitrogen (TN) followed the same trend as nitrate. Lowest concentration (40.4±23.7mg/l) was observed in the river while highest (54.7±18.2mg/l) at the outlet of the wetland. Based on ANOVA test, there was no significant difference among sites (F=0.167, d.f=21, p=0.848).

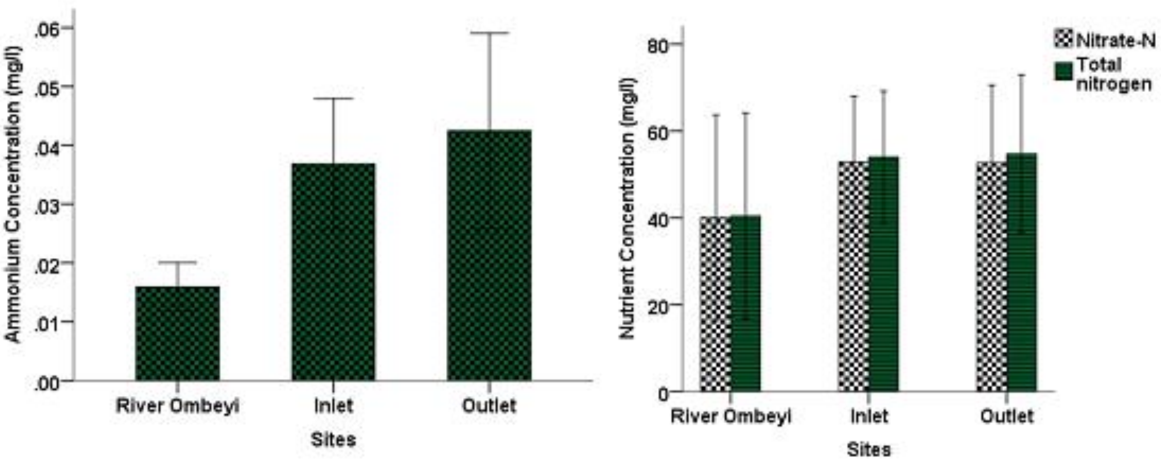


Figure 6: Variation in ammonium, nitrate and total nitrogen concentration in River Ombeyi, inlet and outlet of the wetland. Bars indicates standard error of the mean (n=22).

(c) Variations in SRP, TP and TSS concentration in River Ombeyi, inlet and outlet of the wetland

There was no significant difference (ANOVA; F=0.344, d.f=21, p=0.713) between SRP concentration in the river (0.05±0.01mg/l), inlet (0.07±0.1mg/l) and outlet of the wetland (0.07±0.01mg/l) (Figure 7). The concentration varied from 0.03mg/l to 0.12mg/l in the river, whereas at the inlet and outlet it ranged from 0.04mg/l to 0.13mg/l and 0.04mg/l to 0.15mg/l respectively. TP concentration on the other hand was highest at inlet of the wetland (0.41±0.13mg/l) but lowest in the river (0.19±0.01mg/l). At the outlet of the wetland, TP concentration of 0.34±0.07mg/l was observed. Despite the fluctuations in TP concentration, there was no significant difference among the sites (ANOVA; F=1.472, d.f=21 p=0.254). Phosphorus in the river, inlet and outlet of the wetland were dominated by particulate phosphorus (PP). In the river, 70.8% and 29.2% were observed as PP and SRP respectively.

At the inlet PP was 83.7% and SRP 16.3%, whereas at the outlet 79.3% PP and 20.7% SRP were recorded.

The mean TSS concentration was highest at the inlet compared to the outlet of the wetland and the river (Figure 7). The lowest concentration of 61.2±14.1mg/l was observed in the river. The mean concentrations were 165.8±62.4mg/l and 122.1±40.4mg/l at the inlet and outlet of the wetland respectively. There was no significant difference in TSS concentration among sites (ANOVA; F=1.097, d.f=21, p=0.354).

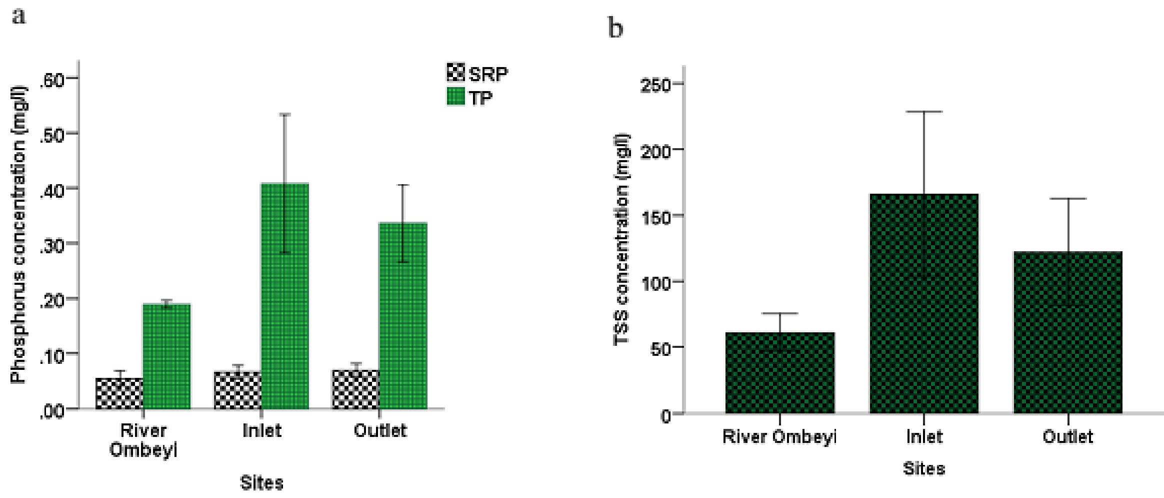


Figure 7: Variation in SRP, TP and TSS concentrations in the river, inlet and outlet of the wetland. Bars indicate standard error of the mean (n=22).

4.5.2 Temporal variation in physico-chemical parameters in Ombeyi natural wetland

(a) Temporal variation of *in situ* measurements; DO, EC, water temperature and pH at the inlet and outlet of the wetland

The mean values for DO, water temperature and EC with their significant variations among the sampling months are presented in figure 8 below. The mean DO concentration at the inlet of the natural wetland varied significantly over time during the study period (ANOVA, F=7.425, d.f=7, p=0.041). Based on Tukey's *post hoc* test, there was no significant variation among sampling months (p>0.05). The DO concentration at the outlet of the wetland on the other hand did not vary significant over time (ANOVA, F=5.598, d.f=7, p=0.065). The mean DO concentration at the inlet of the wetland ranged from 2.9-4.9mg/l while at the outlet it ranged from 2.8-4.9mg/l.

The EC at the inlet of the wetland varied significantly among the sampling period (ANOVA, F=29.345, d.f=7, p=0.003). The highest EC of 136.7µS/cm was observed in March while the lowest of 98.8µS/cm was observed in January. Based on Tukey's *post hoc* test the

EC in December, January and February were similar (p>0.05) while in March it was significantly different from the rest of the months (p<0.05). The EC at the outlet showed similar trend with significant variation among sampling months (ANOVA, F=26.939, d.f=7, p=0.004). Based on Tukey's *post hoc* test the EC in December, January and February were similar (p>0.05) while in March it was significantly different (p<0.05).

Water temperature at the inlet of the wetland showed no significant variation among the sampling period (ANOVA, F=0.268, d.f=7, p=0.846). The outlet of the wetland showed similar trend without significant change among the sampling period (ANOVA, F=0.218, d.f=7, p=0.879). During the sampling session the water temperature ranged from 20.9-29.3ºC at the inlet of the wetland and 20.8-29.8ºC at the outlet of the wetland.

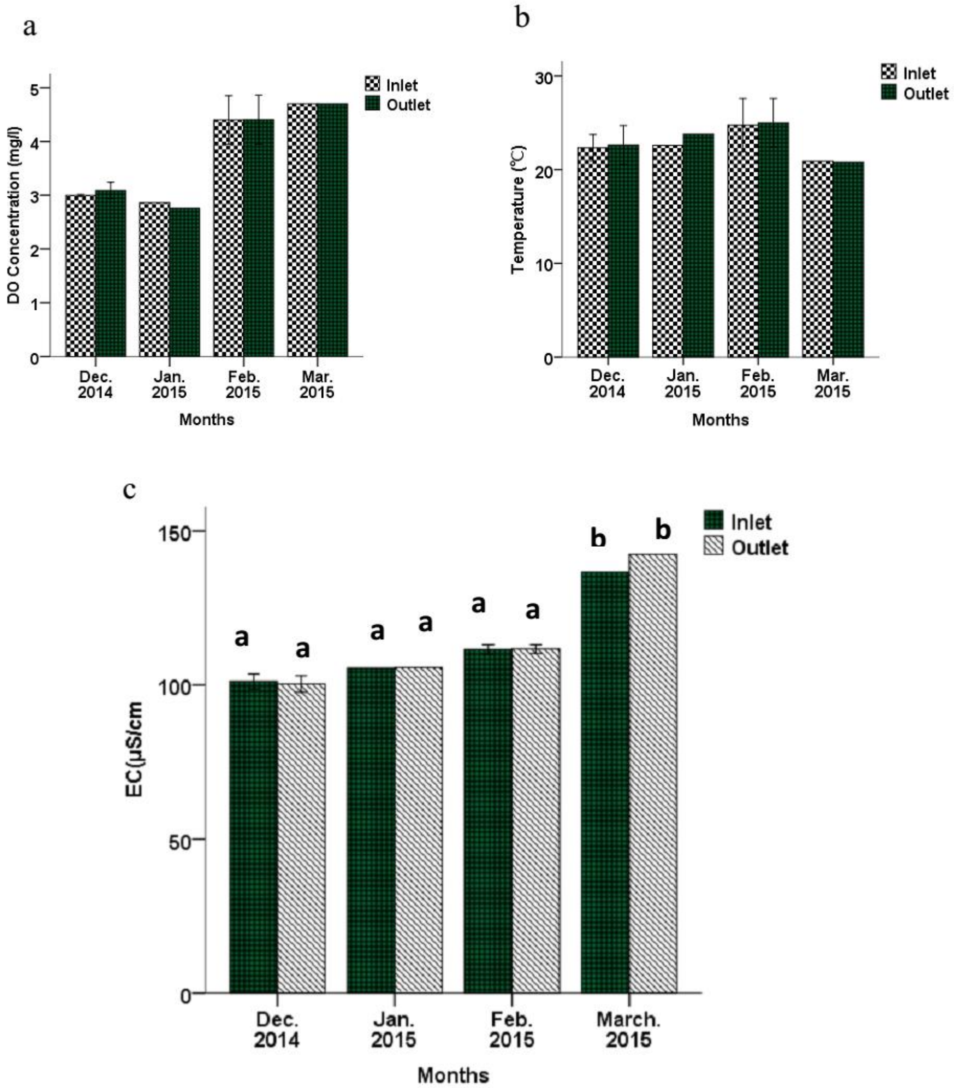


Figure 8: Temporal variation of *in situ* measurements of DO, EC and temperature at the inlet and outlet of Ombeyi natural wetland (values presented as means ±SE, n=8). Bars with the same letters are not significantly different (Tukey's *post hoc* test).

(b) Temporal variation in N, P and TSS concentration in Ombeyi natural wetland

Results for temporal variation in N, P and TSS at the inlet and outlet of the wetland during the study period of December 2014 to March 2015 are presented in figure 9 below. The mean ammonium concentration differed significantly at the inlet of the wetland during the sampling period (ANOVA, F=8.376, d.f=7, p=0.034). The concentration increased from December to March. Based on Tukey's *post hoc* test, the concentration was similar in December, January and February (p>0.05) and significantly different in December and March (p<0.05). At the outlet of the wetland, the ammonium concentration did not differ significantly during the sampling period (ANOVA; F=3.505, d.f=7, p=0.129).

The mean nitrate concentration followed a different pattern from ammonium. The concentration at the inlet of the wetland was highest (76.75±9.36mg/l) in January but lowest in February (10.15±3.00mg/l). However, there was no significant variation in the concentration among the sampling period (ANOVA, F=0.961, d.f=7, p=0.493). The same trend was observed in nitrate concentration at the outlet of the wetland with no significant variation among the sampling period (ANOVA, F=1.434, d.f=7, p=0.357).

The mean TN concentration followed a similar trend as nitrate. The concentration at the inlet of the wetland was highest (80.03±6.5mg/l) in January but lowest in February (10.69±2.9mg/l). However, there was no significant variation in the concentration among the sampling period (ANOVA, F=1.037, d.f=7, p=0.466). The same trend was observed in TN concentration at the outlet of the wetland with no significant variation among the sampling period (ANOVA, F=1.264, d.f=7, p=0.399).

The highest mean SRP concentration was observed in March at the inlet and outlet of the wetland. At the inlet SRP concentration of 0.12±0.02 mg/l was observed, while at the outlet of the wetland the concentration was 0.11±0.04 mg/l. At the inlet of the wetland, there was a significant variation in the concentration among the sampling period (ANOVA, F=11.610, d.f=7, p=0.019). Based on Tukey's *post hoc* test, the concentration was similar in December, January and February (p>0.05) but significantly different between December and March. The mean SRP concentration at the outlet did not vary significantly from December to March (ANOVA, F=1.809, d.f=7, p=0.285).

TP concentration increased from December to March at the inlet and outlet of the wetland. However, the concentration was lower in March at the outlet (0.57±0.15mg/l) compared to the inlet (0.86±0.34mg/l) of the wetland. At the inlet of the wetland, TP concentration varied significantly from December to March (ANOVA, F=10.730, d.f=7, p=0.022). Based on Tukey's *post hoc* test, the concentration was similar in December, January and February (p>0.05) but significantly different between December and March (p<0.05). The TP concentration at the outlet of the wetland followed a similar pattern as inlet of the wetland. The concentration increased from December to March but there was no significant difference among sampling period (ANOVA, F=6.025, d.f=7, p=0.058).

The mean TSS concentration followed a similar pattern as TP. The concentration increased from December to March with the highest concentration observed in March in both inlet (390.50±169.50mg/l) and outlet (267±83mg/l) of the wetland. At the inlet of the wetland, the concentration varied significantly among the sampling period (ANOVA, F=16.722, d.f=7, p=0.010). Based on Tukey's *post hoc* test there was similarity in TSS concentration in December, January and February (p>0.050 but significant difference was observed between December and March. At the outlet of the wetland however, the concentration did not vary significantly among the sampling period (ANOVA, F=2.261, d.f=7, p=0.223). Based on Pearson correlation, there was a significant positive correlation between TSS and TP in both inlet and outlet of the wetland (r=0.960).

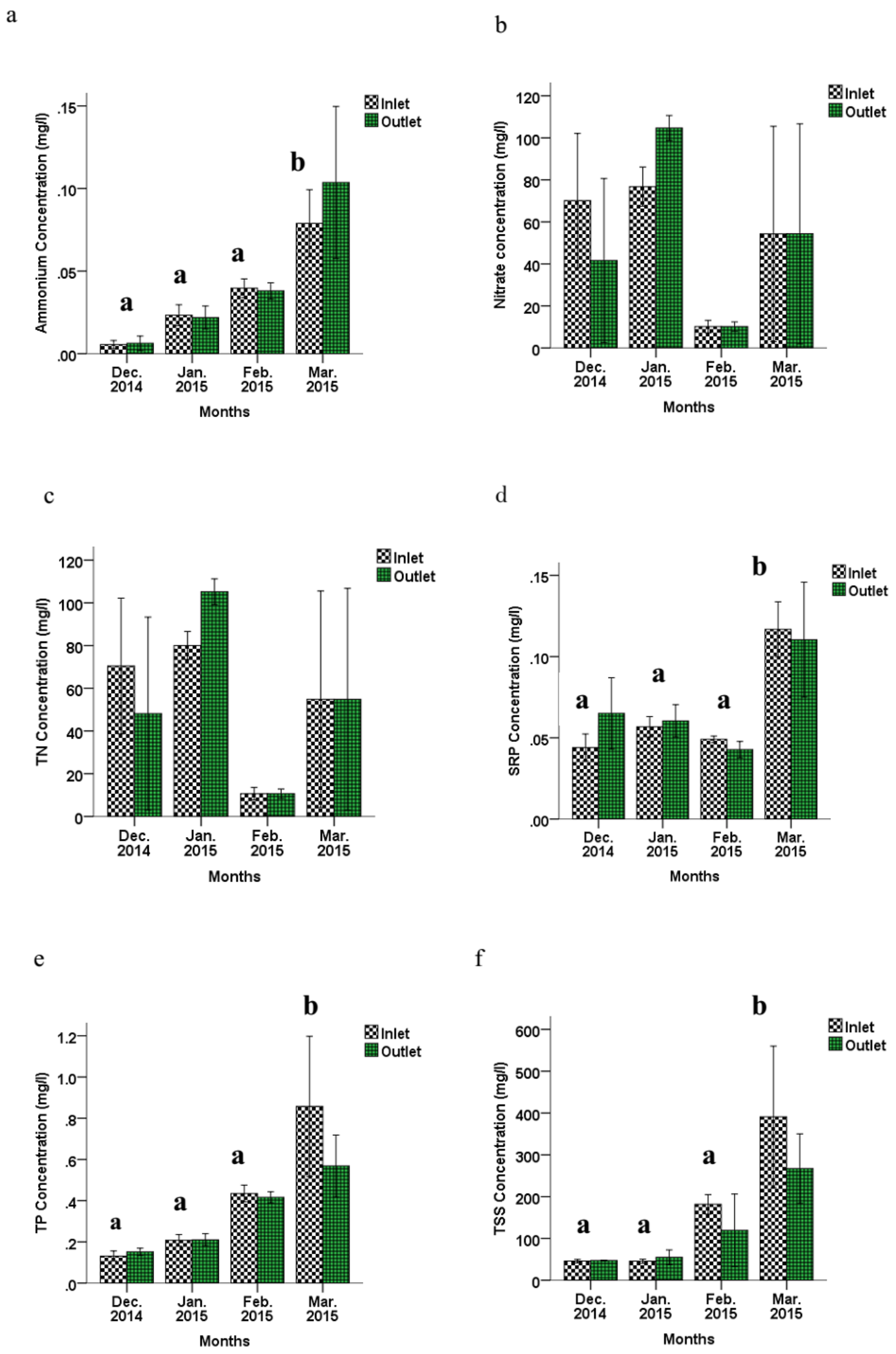


Figure 9: Temporal variation in nutrients and TSS concentration in Ombeyi natural wetland (values presented as means ±SE, n=8). Bars with the same letters are not significantly different (Tukey's *post hoc* test).

4.5.3 Macrophytes biomass and nutrients accumulation

The above ground biomass of papyrus and phragmities harvested in the wetland were 1.6±0.1kgDW/m^2 and 1.4±0.1kgDW/m^2 respectively. Total Nitrogen content of 1.31% DW which was calculated to 0.02kgN/m^2 in papyrus while in phragmities 1.12% TN that is, 0.01kgN/m^2 were observed. TP on the other followed the same trend in papyrus as TN. TP content in papyrus was 0.13% which translates to 0.002kgP/m^2, whereas in phragmities 0.09% (0.001kgN/m^2) was observed.

4.6 Water purification ES in Ahero Irrigation Scheme's rice fields

4.6.1 Spatial variation of physico-chemical parameters in water in Ahero Irrigation Scheme's rice fields

(a) Spatial variation of *in situ* measurements at the inlet, outlet and drainage canal of rice fields

The mean values and ranges for DO, EC, pH and water temperature, at the inlet, outlet and drainage canal of the rice fields during the entire rice growing period from December 2014 to March 2015 were observed. Dissolved Oxygen (DO) was highest at the inlet (6.6±0.1mg/l) but lowest at the outlet (4.1±0.7mg/l). At the inlet, the concentration ranged from 6.1 mg/l to 7.2mg/l, whereas at the outlet the concentration ranged from 0.7 mg/l to 14.2mg/l. At the drainage canal on the other hand, the concentration increased to 5.5±0.9mg/l and ranged from 2.2mg/l to 8.7mg/l. The DO concentration differed significantly among sites; inlet, outlet and drainage canal (ANOVA; F=4.663, d.f= 49, p=0.011). Based on *Tukey's post hoc* test the concentration at the drainage canal was similar to the inlet and outlet of rice fields ($p>0.05$) but significantly different at the inlet and outlet ($p<0.05$).

The mean EC increased from the inlet (360.5±11.8 µS/cm) to the outlet (419.8±15.8 µS/cm) but decreased at the drainage canal (406.8±27.0 µS/cm). At the inlet, the EC ranged from 280.5µS/cm to 445.0µS/cm whereas, at the outlet and drainage canal, it ranged from 270.5µS/cm to 572.5µS/cm and 302.0µS/cm to 526.0µS/cm respectively. Electrical conductivity differed significantly among sites (ANOVA; F=3.950, d.f =49, p=0.026). Despite these differences, there was no significant differences between EC in drainage canal with inlet and outlet ($p>0.05$) but significant variation was noted between EC in the inlet and outlet of rice fields ($p<0.05$).

Water temperature did not vary significant among sites (ANOVA; F=1.348, d.f=49 p= 0.237). pH ranged from 7.8 to 8.7 at the inlet, while at the outlet and drainage canal, it ranged from 7.2 to 9.4 and 7.6 to 8.7 respectively.

(b) Spatial variation in ammonium-nitrogen, nitrate-nitrogen and total nitrogen concentration at the inlet, outlet and drainage canal of rice fields

Results for spatial variation in N concentration at the inlet and outlet of the wetland during the study period of December 2014 to March 2015 are presented in figure 10 below. The ammonium concentration was lowest at the inlet (0.01 ± 0.001 mg/l) and highest at the outlet (0.11 ± 0.02 mg/l). However, the concentration decreased at the drainage canal to 0.03±0.01mg/l. Despite the fluctuations in ammonium concentrations, there were no significant differences among the sites (ANOVA; F=0.906, d.f=49, p=0.411).

Unlike the trend in ammonium concentration, nitrate and TN concentrations were highest at the inlet and lowest at the outlet. At the inlet, mean nitrate concentration was 63.76±12.9mg/l and ranged from 16.32 mg/l to 185.01mg/l. At the outlet of rice fields, the mean concentration was 40.24±11.1mg/l and ranged from 1.54 to 166.96mg/l, whereas at the drainage canal a concentration of 62.01±29.2mg/l which ranged from and 1.13 to 231.04mg/l was observed. Nitrate concentration among sites varied significantly (ANOVA; F=3.758, d.f=49, p=0.031). Tukey's *post hoc* test indicated that the concentration at the drainage canal was similar to the concentration at inlet and outlet of rice fields (p>0.05) but significantly different at the inlet and outlet of rice fields (p<0.05). TN concentrations at the inlet ranged from 17.01 to 185.4mg/l, 2.04 to 167.4mg/l at the outlet and 2.08 to 231.72mg/l at the drainage canal. The concentration among sites varied significantly (ANOVA; F=3.661, d.f=49, p=0.033). Tukey's *post hoc* test indicated that the concentration was similar at the inlet (p>0.05) and drainage canal but significantly different at the outlet (p<0.05).

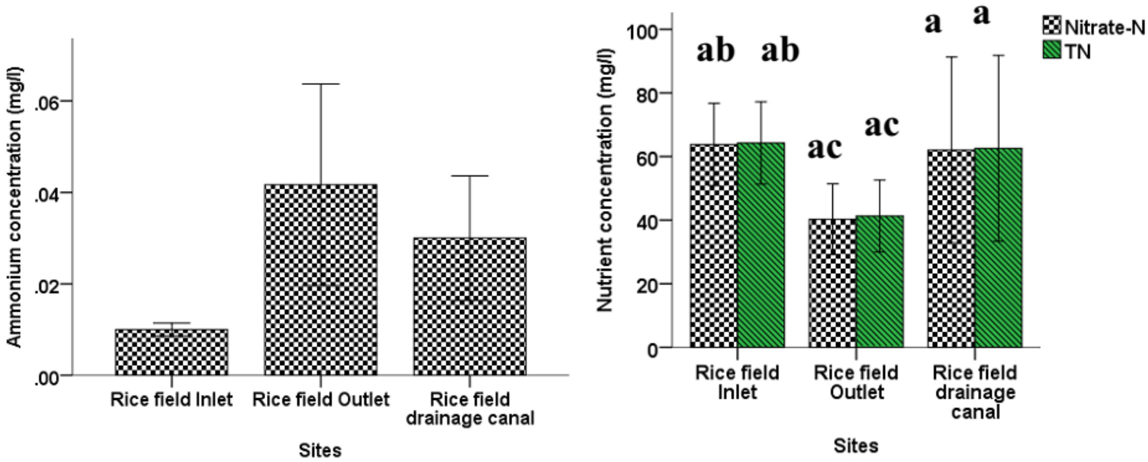


Figure 10: Variation in ammonium, nitrate and total nitrogen concentrations along sampling sites in rice fields. The bars indicate standard error of the mean ammonium, nitrate and total nitrogen concentration (mg/l) (n= 50). Graphs with the same letters are not significantly

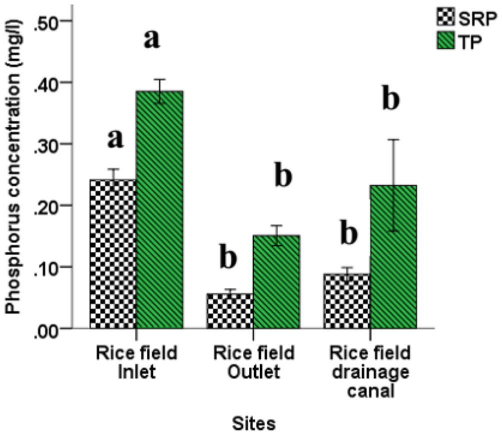
different from each other, that is, letters ab and ac denotes sites with significant differences in nitrate and TN concentrations ($p<0.05$) while a indicate sites with similar concentrations ($p>0.05$).

(c) **Spatial variation in SRP, TP and TSS concentration at the inlet, outlet and drainage canal of rice fields**

The SRP concentration was highest at the inlet (0.24±0.02mg/l) but lowest at the outlet (0.06±0.01mg/l) of the rice fields (Figure 11). The concentration at the inlet ranged from 0.09 to 0.33mg/l, whereas at the outlet and drainage canal ranged from 0.01 to 0.20mg/l and 0.05 to 0.15mg/l respectively. The SRP concentration varied significantly among sites; inlet, outlet and drainage canal (ANOVA; F=66.804, d.f=49, p=0.000). Tukey's *post hoc* test indicated that the concentration varied significantly at the inlet ($p<0.05$) but was similar at the outlet and drainage canal ($p>0.05$).

TP followed the same pattern as SRP with concentration being highest at the inlet (0.39±0.02mg/l) and lowest at the outlet (0.15±0.02mg/l) (Figure 11). The concentration at the inlet ranged from 0.23 to 0.49mg/, whereas at the outlet and drainage canal it ranged from 0.08 to 0.41mg/l and 0.11 to 0.71mg/l respectively. There was significant differences in TP concentrations among sites (ANOVA; F=25.789, d.f=49, p=0.000). Turkey's *post hoc* test showed similarity between outlet and drainage canal ($p>0.05$) and significant difference at the inlet of the rice fields ($p<0.05$). Phosphorus at the outlet and drainage canal of rice fields were dominated by particulate phosphorus (PP) of which at the outlet, 63.2% and 38.8% were observed as PP and SRP respectively. In the drainage canal PP was 62.2% and SRP 37.8%, whereas at the inlet of rice fields 37.5% PP and 62.5% SRP were observed.

Total Suspended Solids (TSS) concentration was highest at the inlet (54.08 ± 6.4 mg/l) but lowest at the outlet of the rice fields (22.90 ± 7.4 mg/l). However, there was an increase in TSS at the drainage canal (33.26 ± 15.8 mg/l). At the inlet, TSS ranged from 15.7 mg/l to 120.5 mg/l, whereas at the outlet and drainage canal TSS ranged from 1.7 mg/l to 120 mg/l and 3.0 to 124.4 mg/l respectively. The TSS concentration among sites varied significantly (ANOVA; F=12.320, d.f=49, p=0.000). Tukey's *post hoc* test indicated that the concentration was similar at the outlet and drainage canal ($p>0.05$) but significantly different at the inlet ($p<0.05$).



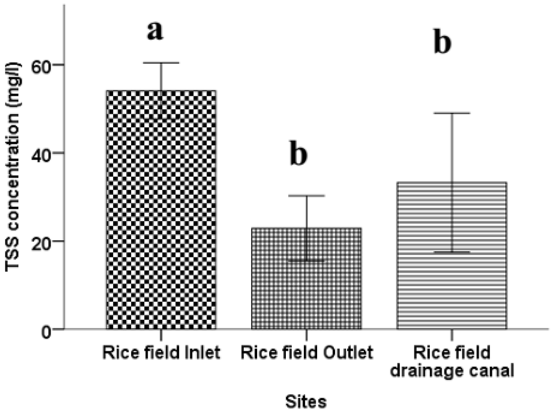


Figure 11: Variation in SRP, TP and TSS concentrations along sampling sites in rice fields. The means and standard errors of SRP, TP and TSS concentrations (mg/l) are shown for each sampling site (n=50). The sites with significant differences in SRP, TP and TSS concentrations are denoted by superscript ab ($p<0.05$) while b denotes sites with similar concentration at $p>0.05$.

4.6.2 Temporal variation in N, P and TSS at the inlet, outlet and drainage canal of rice fields

Results for temporal variations in N, P and TSS during the study period of December 2014 to February 2015 are presented in figure 12 below. The mean ammonium concentration at the inlet of the rice fields did not vary significantly during the sampling period (ANOVA; F=0.00, d.f=6, p=1.000). The concentration in the drainage canal followed similar pattern over time without significant variation from December to February (ANOVA; F=2.007, d.f=6, p=0.249). The concentration at the outlet of the rice fields followed a different pattern from inlet and drainage canal of rice fields with significant variation among sampling periods (ANOVA; F=30.055, d.f=6, p=0.004). The concentration was highest (0.14±0.08mg/l) in December and lowest (0.01mg/l) in February. Tukey's *post hoc* test showed that the concentration in January was similar to December and February ($p>0.05$) but significant variation between December and February ($p<0.05$).

The mean nitrate concentration at the inlet of rice fields was not significant different during the sampling period (ANOVA; F=1.658, d.f=6, p=0.299). The concentration at the outlet of rice fields also did not vary significantly among the months (ANOVA; F=0.535, d.f=6, p=0.622). The concentration at the drainage canal followed the same trend as inlet and outlet without significant variation among the sampling months (ANOVA; F=0.329, d.f=6, p=0.738). The mean TN concentration followed the same trend as nitrate. At the inlet of rice fields, the concentration was not significant different during the sampling period (ANOVA; F=1.673, d.f=6, p=0.296). The concentration at the outlet of rice fields also did not vary significantly among the months (ANOVA; F=0.582, d.f=6, p=0.600). The concentration at the drainage canal followed the same trend as inlet and outlet without significant variation among the sampling months (ANOVA; F=0.345, d.f=6, p=0.727).

The mean SRP concentration at the inlet increased throughout from December to February. A significant increase was observed over time (ANOVA; F=37.446, d.f=6, p=0.003). Tukey's *post hoc* test showed significant difference in concentration in all months (p<0.05). The concentration at the outlet was not significantly different over time (ANOVA; F=0.299, d.f=6, p=0.757). The concentration at the drainage canal also did not vary significantly during the sampling period (ANOVA; F=4.313, d.f=6, p=0.100).

The mean TP concentration at the inlet of rice fields showed no variation significant over time (ANOVA; F=4.227, d.f=6, p=0.103). At the outlet of the rice fields, the concentration varied significantly among the sampling period (ANOVA; F=41.827, d.f=6, p=0.002). The highest concentration of 0.26±0.03mg/l was observed in December and lowest (0.09mg/l) in January. Based on Tukey's *post hoc*, the concentration was similar in January and February (p>0.05) but significantly different in December (p<0.05). The concentration in drainage canal followed the same trend as outlet of rice fields showing similarity in concentration in January and February (p>0.05) but significantly different in December (p<0.05).

The mean TSS concentration decreased in all sites from December to March. The concentration at the inlet of rice fields during irrigation was highest (80±95mg/l) in December and lowest in February (39.6±4.10mg/l). The concentration varied significantly among the sampling period (ANOVA; F=10.319, d.f=6, p=0.026). Based on Tukey's *post hoc* test, the concentration was similar in January and February (p>0.05) but significant variation was observed in December (p<0.05). The concentration at the outlet of rice fields followed similar trend as inlet with significant variation among sampling period (ANOVA; F=7.848, d.f=6, p=0.041). The highest concentration of 58.55±13.25mg/l was observed in December while the lowest concentration of 7.13±0.46mg/l in February. Based on Tukey's *post hoc* test, there was a similarity in concentration in February with December and January (p>0.05) but significant variation between December and February (p<0.05). The drainage canal followed the same trend as outlet over time. The TSS concentration was significantly different among sampling period (ANOVA; F=16.816, d.f=17, p=0.011). Based on Tukey's *post hoc* test, there was similarity in concentration in January and February (p>0.05) but significant difference was observed in December (p<0.05).

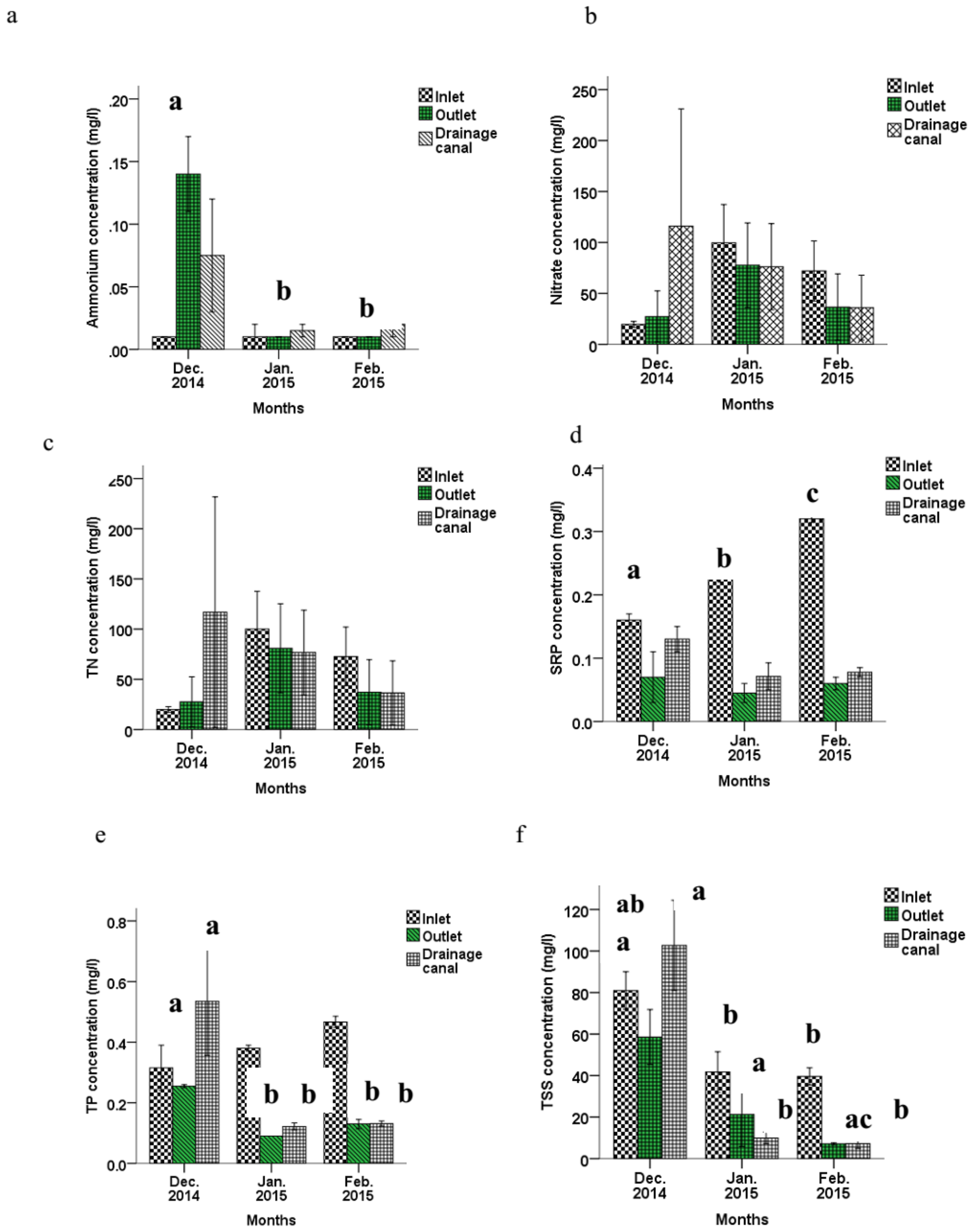


Figure 12**:** Temporal variation in nutrients and TSS concentration in rice fields (values presented as means ±SE, n=6). Bars with the same letters are not significantly different (Tukey's *post hoc* test).

4.6.3 Biomass and nutrient uptake by rice plants

The above ground biomass of rice plants harvested increased as the rice grew. On the first harvesting the biomass was 2.1±0.03kg DW/m^2 while by the end of the growing season, the biomass increased to 3.2±0.33kg DW/m^2. Overally, the biomass of rice plants observed in the entire rice fields was 12.95tonnes/acre.

Conversely, to biomass of rice plants, nutrients contents in rice plants reduced with increasing age of the plants. On the first harvesting of rice plants (two months old), TN content of 2.6% DW, translating to 53.8Ng/m^2 (217.7kgN/acre) while TP of 0.6% DW that is, 4.6Pg/m^2 (18.6kgP/acre) were recorded, whereas on the second harvesting (three and half months old) TN content of 1% DW, translating to 30.5Ng/m^2 (25.5kgN/acre) while TP of 0.02Pg/m^2 (0.08kgP/acre) were observed.

4.6.4 Nutrients and TSS loadings into River Ombeyi from rice fields' drainage canal in Ahero Irrigation Scheme

The amount of nutrients discharged into River Ombeyi from rice fields through drainage canal ranged from 0.01to 31g/day. Sediment loading on the other hand was 16g/day and a discharge of 0.01m^3/s was observed (Table 6). Higher loadings of nitrate and TN into River Ombeyi were observed compared to SRP, TP and TSS.

Table 6: Nitrogen, phosphorus and TSS loadings into River Ombeyi from rice fields' drainage canal

Variable	Concentration (mg/l)	Load (g/day)
TSS	33.36	16.59
NH_4-N	0.03	0.02
NO_3-N	62.01	30.84
TN	62.5	31.08
SRP	0.10	0.05
TP	0.23	0.11

4.7 Nutrients and sediment loading and retention (%) in Ombeyi natural wetland and rice fields in Ahero Irrigation Scheme

Nutrients and sediments loads were higher at the inlet than the outlet of the natural wetland indicating retention. In the natural wetland, more phosphorus was retained compared to nitrogen whereby 28.8% SRP and 50% TP were retained while for nitrogen, 19.6% nitrate, 25% ammonium and 19.1% TN were retained (Table 7). Nutrients retention in the wetland in relation to concentration showed that the wetland was a source of both nitrate and TN while for other TSS, SRP and TP were retained indicating sink function of the wetland.

In the rice fields, there was higher nutrients and TSS concentration at the inlet than outlet of the rice fields indicating retention except for ammonium which indicated source (Table 8). Nonetheless, based on chi-square test there was no significant difference in ammonium retention in Ombeyi natural wetland and rice fields in Ahero Irrigation Scheme (X^2=5.024,d.f=1, $p>0.05$). Nitrate, TN, SRP, TP and TSS on the other hand indicated significant difference between the sites (X^2=5.024, d.f=1, $p<0.05$).

Table 7: Nitrogen, phosphorus and TSS concentrations, loads and retention in Ombeyi natural wetland

Variables	**Concentration (mg/l)**		**Load (Kg/Day)**		**Nutrient retention (%)**	
					Loading (%)	Concentration (%)
	Inlet	Outlet	Inlet	Outlet		
TSS	165.8	122.1	1.58	0.86	45.6*	26.36
NH_4-N	0.04	0.04	0.0004	0.0003	25	0
NO_3-N	48.17	52.67	0.46	0.37	19.6	-9.34
TN	49.34	54.69	0.47	0.38	19.1	-10.84
SRP	0.07	0.07	0.0007	0.0005	28.8	0
TP	0.41	0.33	0.004	0.002	50*	19.51

* Highest retention capacity; TP and TSS

Table 8: Nutrients TSS concentration and retention in rice fields in Ahero Irrigation Scheme

Variable	**Concentration (mg/l)**		**Nutrient retention (%)**
	Inlet	Outlet	
TSS	54.80	22.90	58.21*
NH_4-N	0.01	0.04	-300.00**
NO_3-N	63.75	40.23	36.89
TN	64.23	41.29	35.72
SRP	0.24	0.05	79.16*
TP	0.38	0.15	60.52*

*Indicates a retention >50% while ** Indicates source from the rice fields

4.7.1 Relationship between nutrients and TSS at the inlet and outlet of Ombeyi natural wetland and rice fields in Ahero Irrigation Scheme

Ammonium concentration was negatively correlated to TN and NO_3-N concentration in both natural wetland and rice fields (Table 9). The correlation though was not significant in both sites. Nitrate and TN were both significantly positively correlated, whereas TP, SRP and TSS concentration showed significant correlation in both natural wetland and rice fields. At the outlet of rice fields there was a significant positive correlation between TP and TSS.

Table 9: Correlation matrix between nutrients and TSS concentrations at the inlet and outlet of the natural wetland and rice fields in Ahero Irrigation Scheme

	Inlet of natural wetland			Outlet of natural wetland		
	NH_4-N	NO_3-N	TN	NH_4-N	NO_3-N	TN
NH_4-N	1	-0.450	-0.449	1	-0.353	-0.372
NO_3-N	-0.450	1	0.999**	-0.353	1	0.997**
TN	-0.450	0.999**	1	-0.372	0.997**	1

	Inlet of natural wetland			Outlet of natural wetland		
	SRP	TP	TSS	SRP	TP	TSS
SRP	1	0.892**	-0.872**	1	0.627	0.682
TP	0.892**	1	0.995**	0.627	1	0.904**
TSS	0.872**	0.995*	1	0.682	0.904**	1

	Inlet of rice fields			Outlet of rice fields		
	NH_4-N	NO_3-N	TN	NH_4-N	NO_3-N	TN
NH_4-N	1	-0.165	-0.165	1	-0.175	-0.176
NO_3-N	-0.165	1	0.739**	-0.175	1	0.527**
TN	-0.165	0.739**	1	-0.176	0.525**	1

	Inlet of rice fields			Outlet of rice fields		
	SRP	TP	TSS	SRP	TP	TSS
SRP	1	0.845**	-0.747**	1	0.096	0.379
TP	0.845**	1	-0.548*	0.096	1	0.670**
TSS	-0.747**	-0.548*	1	0.379	0.670**	1

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

* Correlation is significant at the 0.05 level (2-tailed)

CHAPTER FIVE

DISCUSSION

5.1 Historical overview and present status of Ombeyi natural wetland

According to the community members in Kore Irrigation Scheme, the currently named Ombeyi natural wetland historically did not exist in the 1950s. During that period there were a few macrophytes majorly papyrus which were restricted to a narrow strip along River Ombeyi. The heavy rains experienced during 1962-1963 popularly known as" Uhuru rains" resulted to flooding beyond the river floodplains which enabled the macrophytes to expand landward, hence the current wetland situation. Many people in Kore Irrigation Scheme still believe that their historical homes are submerged in the wetland. The residents' recollected to higher grounds due to the 1962-3 heavy rains and subsequent floods concurred with published data of heavy rains in Lake Victoria basin during that period. For instance, Institute of Hydrology (1984) reported an increase in rainfall in 1961 from 1281mm in 1949 to 2201mm in Lake Victoria basin. Moreover, Stager *et al.* (2007) reported heavy rains in the region of approximately 1600mm in 1960s while, Conway (2002) stated that towards the end of 1961 heavy rains experienced in the region caused wide spread flooding within the Lake Victoria basin.

Accordingly this heavy rainfall pattern and flooding in 1960s resulted into establishment of Ombeyi natural wetland and also affected River Ombeyi which frequently overtops its banks and frequently floods the surrounding farms and settlements thereafter. Flooding has become a common phenomenon in Ombeyi location. In order to control flooding in the area, a canal diverting part of water from River Ombeyi to the wetland was constructed by a Japanese company locally known as Degus in 1984 to convey excess water from the river away from settlement areas during rainy seasons a situation that led to drying out of part of Ombeyi natural wetland and land reclamation for rice production in Ombeyi location. To date, conversion of Ombeyi natural wetland into rice fields and most recently arrow roots (yams) continues inevitably. However, both systems; the natural wetland and rice fields provide varieties of ES to the community and thus enhancing livelihoods.

5.2 Provisioning ES derived from Ombeyi natural wetland: Impacts of natural wetland conversion to rice fields on ES

Mats made from papyrus are some of the key ES derived from Ombeyi natural wetland by the local community and many local residents are engaged in papyrus mat making and generate income from them. Generally the local mat makers can obtain a gross income ranging from KES 22,124.10- 62,343.30 from sale of mats per year. But the due to increased rice production area into wetland areas and over-harvesting of papyrus biomass by mat makers area under papyrus has reduced leading to decline in the number of mats produced by Ombeyi mat makers from about 35 mats to 6 in the last 10 years. Moreover, FGD also disclosed that the continued land ownership dispute and the local belief that the floods caused by "Uhuru rains" of 1962-63 created Ombeyi natural wetland leading to loss of farm land for the local residents has caused loss of the wetland areas. Thus drainage and conversion of the natural wetland into rice fields and other agricultural lands is seen as a means of recovering their lost land. The reduction in number of mats has led to decrease in income generated from mat production which infers a decline in the ES provided by the natural wetland. Information from the FGD revealed that many mat makers were either contemplating leaving the business or had already left and ES derived from natural papyrus stands is already being lost.

Reeds are a common wetland macrophyte found in Ombeyi wetland. They provide a variety of ES to local community as shown by their indicators of measurements. The cost of a bundle of reeds required for any of the services like fencing, house roof thatching among others was relatively cheap. This may be attributed to their current (2015) minimal utilization. According to FGD the previous use of reeds and even grass (*Cyperus sinensis*) for house roof thatching in the past years has today been replaced by iron sheets. This is due to changes in community lifestyle and declining area under this macrophyte in Kore Irrigation Scheme and associated wetlands. Moreover, the decrease in wetland size as a result of conversions into rice fields among others not only affected papyrus but also reeds and grass and hence leading to occasional utilization of both macrophytes.

Wetland fisheries in Nyando wetlands is one of the areas that has not been well documented especially its contribution to household economies (Kipkemboi *et al.*, 2007; Okeyo-Owuor *et al.*, 2012). This has been due to seasonal variability of wetland fishing coupled with dominance of subsistence fishing in the wetlands. In Ombeyi natural wetland, fish is one of the ES derived from the wetland by nearly half (41.8%) of the local population as revealed by the responses. The low practise of wetland fisheries was mainly attributed to the scarcity of fish in the wetland as a result of over-fishing, catching of juvenile fish like catfish as bait for Nile perch fisheries in Lake Victoria, habitat (wetland) destruction (conversion into agricultural land and burning) and frequent droughts. These causes of reduction in fish population in Ombeyi natural wetland are not exclusive to this wetland as similar challenges were documented in the entire Nyando Wetland area (Lung'Ayia *et al.*, 2001; Masese *et al.*, 2012; Rongoei *et al.*, 2013).

According to FGD, in 1970s, several fish were found in the area in abundant quantities when Ombeyi wetland was still intact and had not been encroached by agricultural activities. During that period fishing was majorly done for subsistence purposes. The fish species harvested then included; lungfish (*Protopterus aethiopicus*), catfish (*Clarias gariepinus*), tilapia (*Oreochromis niloticus*), Longtail spiny eel (*Mastercembelus frenatus*), Ripon barbel (*Barbus artianalis*) and Luambwa barb (*Barbus cercops*) among others. Nonetheless, currently (2015), the number of fish species have declined roughly to three common species; catfish, lung fish and tilapia. Therefore a local fisherman now get relatively low gross income from fishing activity approximately KES 34,575.30 per year since the fish caught are fewer and smaller in size compared to 1970s. The study finds that wetland fishing is only a part time activity done only in rainy seasons as a result of floods in the area and hence may have contributed to the relatively low gross income.

The low population of wild games used as food may be attributed to migration to other areas caused by anthropogenic activities such as wetland burning by poachers and conversion of wetlands into rice fields. Moreover, over-exploitation of wild games through hunting was also reported. Reduction in wetland animals used as food such as Sitatunga (*Tragelaphus spekei*) and hippos (*Hippopotamus amphibious*) as result of loss of wetland areas due to land reclamation has also been reported by Obiero *et al.* (2012b) in Nyando wetland. Human wildlife conflict is also reported in Nyando wetland as a result of wetland encroachment by human activities such as farming.

5.3 Provisioning ES in rice fields in Kore Irrigation Scheme

Rice production started in Kore Irrigation Scheme as early as 1948. During this period rice farming was rain fed and practised in a very small scale through broadcasting. The large scale rice production began after channelization of River Ombeyi in 1984 to control floods in the area. This caused drying out of part of Ombeyi natural wetland and resulted into motivation of the residents to start large scale rice production through clearing the wetland and even draining parts that still was inundated.

Rice production in Kore Irrigation Scheme was majorly for commercial purposes. The high gross income generated from rice production per farmer of KES 61,488.90 showed that farmers were earning relatively more money from rice farming than utilization of natural wetlands. This high income from rice production has probably been the motivation for more conversion of the wetland into rice fields. However, it is important to note that this is gross income and may not reflect net value of rice fields to the farmers.

Fishing in rice fields is a major activity in Kore Irrigation Scheme as indicated by majority of the respondents (76.9%). On average a farmer who fish in paddy fields may earn a gross income of KES 55,583 per year. The highest income generated was by lung fish (*Protopterus aethiopicus*) as compared to catfish (*Clarias gariepinus*) and tilapia (*Oreochromis niloticus*). The reason may be due to the large size of lungfish obtained as indicated in their pricing. The relatively low pricing of tilapia and catfish may due to their small sizes caught, especially the juveniles of catfish which are used as bait in Nile perch fishery in Lake Victoria. Tilapia juveniles caught on the other hand are being sold to aquaculture farms in the area for pond stocking.

Though fishing for wild fish took place in rice fields, FGD stated that the ES was not being generated in all farms and fishing was more prone in rice fields close to the natural wetland. In addition, rice fields' fishery was supplemented by fishing in irrigation and drainage canals. According to Bakker and Matsuno (2001) fishing in the drainage or irrigation canals of rice fields is one of the unrecognized services of rice fields. Therefore in this study fishing in the drainage and irrigation canals was considered as part of rice fields' fisheries.

5.4 Impacts of natural wetlands and rice fields on cultural ES

According to Obiero *et al.* (2012a) wetlands' resources are linked with religious/spiritual beliefs and therefore there conservation and sustainable utilization should be upheld by riparian communities. In Ombeyi natural wetland, low religious/ spiritual uses of the wetland reported was probably due to the low or declining water levels in the wetland pools, as a result of hydrological alterations. Previously, the deeper water pools were used to carry out some of the activities such as baptism and traditional cleansing. However, wetland degradation was indicated by FGD as not being the main reason behind low utilization for religious/spiritual purposes. Most residents as stated by FGD were not upholding the Luo community traditions and culture which were valuable to the community in the past years due to change in living style among community members. Thus, changes in upholding of cultural norms have further lowered value of the wetlands. High religious/spiritual uses of the rice fields on the other hand may be attributed to the fact that majority of the respondents were rice farmers and hence maximum production was one of their priorities.

Natural wetlands and rice fields are characterized by beautiful landscapes and rich biodiversity and thus supply ES such as aesthetic, ecotourism and educational excursions/activities (MEA, 2005; Yoon, 2009; Raburu *et al.*, 2012). In both Ombeyi natural wetland and rice fields ecotourism was low based on the frequency of tourists both domestic and international visiting both systems in a year. This was mainly attributed to wetland destruction contributing to migration of wild animals which attracted tourists to the area. Moreover, the population of macrophytes in the area has also reduced. Focus Group Discussion (FGD) stated that in the past years when the wetland was still intact, wild animals were numerous in the wetland and hence ecotourism was common in the area. The destruction of the wetland also contributed to the aesthetic values being medium in the wetland.

Recreational ES derived from the natural wetland and rice fields were low and high respectively. Swimming as the recreational activity, was commonly practised in irrigation and drainage canal of rice fields. In the wetland on the other hand, pools of water which were used for such activity previously have dried up.

5.5 Water purification in natural wetlands

Generally, lack of significant variation in physico-chemical parameters; DO, water temperature, pH and EC observed at the inlet and outlet of Ombeyi natural wetland and also in the river may be attributed to limited interactions between water flowing through the wetland with its components such as macrophytes, soil and microbes. The diverted portion of River Ombeyi which flows to Kore Irrigation Scheme and adjacent Ombeyi natural wetland is restricted in a channel. This channelization of the river hinders interaction of macrophytes and other biota with the water flowing through the wetland thereby contributing to the limited changes in physico-chemical variables, especially nutrients concentration in the water.

The low oxygen concentrations recorded in this study is characteristic of most wetlands as also observed by Adhiambo (2013) in Mereronyi wetlands in Kenya. The slightly high DO concentration observed at the inlet of the wetland though not significantly different from the river and outlet of the wetland may be due to relatively low temperature at the site as a consequent of shading effect of macrophytes bordering the river channel. Furthermore, high oxygen demand required by decomposition of organic matter in the wetland may also reduce oxygen concentration in the water (Kansiime and Nalubega, 1999).

According to Reddy *et al.* (1999) respiration and photosynthesis are capable of influencing CO_2 in water which in turn influences the pH to either alkaline or acidic level. When respiration exceeds photosynthesis pH is lowered and vice-versa. This suggests that the alkaline pH (7.5-8.3) values reported in Ombeyi natural wetland may be attributed to photosynthetic assimilation of CO_2 in the water and thus decreasing CO_2 concentration which in turn influences the pH. The pH value reported in this study was comparable to the studies done by Mayo *et al.* (2013) in Mara River Basin Wetland.

The electrical conductivity observed in the wetland ranged between 97.7µS/cm to 142.4µS/cm. This values are within the ranges reported by Adhiambo (2013) in Mereronyi wetland in Kenya but are lower than values reported by studies done by Kelderman *et al.* (2007) and Kanyiginya *et al.* (2010) in Ugandan wetlands used for wastewaters treatment which ranged from 190µS/cm to 590µS/cm. The relatively high EC at the inlet and outlet of the wetland generally may be as a result of human activities such as use of seining method for fishing in River Ombeyi especially in March when fishing coincided with sampling dates resulting to re-suspension of adsorbed nutrients especially P back into the water and thus increasing ionic concentration in the water.

In relation to nutrients and TSS retention, natural wetlands are widely known for their water purification function. This fact has led to many initiatives to restore natural wetlands or build constructed ones with an intention of improving water quality (Verhoeven *et al.*, 2006). However, in Ombeyi natural wetland nutrients and sediments concentrations at the inlet and outlet of the wetland were not significantly different. Furthermore, comparison of the nutrients and TSS concentrations to that of River Ombeyi before diversion into the wetland also showed no significant difference. According to Junk (2002) connectivity of wetlands to water bodies is essential for nutrient cycling and sediments flux and thus hydrologic alterations such as channelization affect such processes.

The higher ammonium concentration at the outlet of the natural wetland maybe due to aerobic condition at the site because it is an open channel and thus organic nitrogen may have been converted to ammonium. Ammonification occurs in oxygenated zones and declines as the conditions changes to anaerobic conditions. The high NO_3-N concentration observed at the outlet of the wetland may be due to oxidation of ammonium to nitrate by nitrifying bacteria as a result of presence of oxygen (3.8mg/l) in the water from atmospheric input and leakages from macrophytes roots. Nitrification usually occurs in aerobic conditions of which ammonium is oxidized to nitrate (Verhoeven *et al.*, 2006; Hefting *et al.*, 2013).

According to Lai and Lam (2008) soil sorption is the primary source of P retention in wetlands. However, adsorbed P may be released into the water column through desorption influenced by bioturbation and sediment re-suspension (Reddy *et al.*, 1999). Therefore, the higher SRP concentrations observed in the wetland especially in March 2015 may be due re-suspension of adsorbed P into water column as result of sediment disturbance during fishing in the river flowing through the wetland. The low TP concentrations observed at the outlet of the wetland on the other hand may be due to adsorption and sedimentation of TSS. Particulate Phosphorus (PP) constituted the higher portion of P as compared to SRP that is, 83.7% at the inlet and 79.3% at the outlet. Moreover, there was a significant positive correlation between TSS concentration and TP. This implies that as sediments settled as a result of low water velocity of 0.08m/s at the outlet, PP was also removed together with TSS.

In wetlands, macrophytes play an important role in nutrients uptake and subsequent incorporation into their biomass (Reddy *et al.*, 1999; Mugisha *et al.*, 2007). The storage of nutrients by macrophytes is a key process in the removal of nutrients in water and thus enhancing water quality. As the macrophytes take up nutrients their biomass also increases since nutrients are required for cell development during growth (Kanyiginya *et al.*, 2010). In Ombeyi natural wetland, TN content of 1.31% DW and 1.12% DW reported in papyrus and phragmities respectively, may explain the high biomass of 1.6kg DW/m^2 and 1.4kg DW/m^2 for the respective macrophytes. The biomass reported in this study for papyrus are comparable to the findings of Kanyiginya *et al.* (2010) on nutrients retention in Natete wetland in Uganda of approximately 1kgDW/m^2 at the outlet of the wetland. However, the biomass reported in this study for *Cyperus papyrus* and *Phragmites australis* are lower than the findings of Mugisha *et al.* (2007) on phytomass accumulation of macrophytes in Nakivubo and Kirinya wetlands that indicated biomass of 2.48 kg DW/m^2 and 3.29 kg DW/m^2 for papyrus and 1.79 kgDW/m^2 and 3.03 kgDW/m^2 for phragmities. This difference in biomass of the macrophytes may be due to the fact that the wetlands were used for wastewater treatment and therefore have high concentration of nutrients available for plants growth compared to this site where the water had relatively lower nutrients concentration with limited interactions with macrophytes due to river channelization.

5.6 Water purification ES in Ahero Irrigation Scheme's rice fields

The low DO concentration observed at the outlet of rice fields may be due to inhibition of atmospheric input of oxygen as the biomass of rice increases with growth. The alkaline pH observed in rice fields especially on the first month of growth may be attributed to photosynthesis from phytoplanktons and benthic algae exceeding respirational oxygen demand of zooplanktons and other organisms present in the rice fields. Respiration and photosynthesis are capable of influencing CO_2 concentration in water which in turn influences the pH to either alkaline or acidic level (Forés and Comín, 1992; Reddy *et al.*, 1999). Forés and Comín (1992) states that during tillering phase of rice growth, phytoplanktons dominate the rice fields and through photosynthesis CO_2 is utilized and thus influencing pH to alkaline levels. The dominance of phytoplankton is also shown by high concentrations of DO (7mg/l) observed at the outlet during that period. The decreasing levels of pH in the rice fields after first month of growth however, may be attributed to respiration surpassing production as observed in low oxygen concentrations at the outlet from January to March 2015.

Electrical conductivity was highest at the outlet due to application of fertilizer in the rice fields which may have increased ionic concentration in the water. The same applies to increase in EC throughout the months of rice growing whereas the gradual increase at the inlet may be due to nutrients inputs in River Nyando from the catchment. Okeyo-Owuor *et al.* (2012) stated that River Nyando catchment covers an area of approximately 3,600 km^2 and constitutes agricultural activities and industries. Therefore, surface runoff during the occasional rains and discharge from the industries may have contributed to the high EC observed at the inlet of the rice fields.

In relation to nutrients and TSS retention, rice fields are capable of purifying incoming water due to their ability to act as artificial wetlands (Matsuno *et al.*, 2006; Zhang *et al.*, 2007; Yoon, 2009). In Ahero Irrigation Scheme, the high ammonium concentration observed at the outlet especially during the first month (December) of growth of rice was probably due to fertilizer (ammonium sulphate and urea) applications in rice fields during that period. Approximately 100kgN/acre was applied in the rice fields. Urea fertilizer applied in the rice fields contains 21% N while ammonium sulphate 26%N. This implies that during the entire rice growing period roughly 23.5kg of N was applied in the rice fields. Moreover, oxygen concentrations reduced at the outlet and that may have contributed to ammonium accumulation at the outlet. Nitrate on the other hand was lowest at the outlet may be due to rice plants uptake as the water flows through the rice fields because of its bio-availability. In addition, Verhoeven *et al.* (2006) states that oxidation of ammonium to nitrate through nitrification processes occurs in presence of oxygen and thus, the low nitrate concentrations at the outlet maybe due to low oxygen concentrations obtained at the site, thus limiting nitrification process.

The high TN concentration observed throughout the sampling period was mainly contributed by nitrate concentrations. This probably was due to burning of straws after rice harvesting and thus contributing to less organic matter being returned to the soil. According to Maruyama *et al.* (2008) rice straws are dominant inputs of N into the soil. Thus burning of straws which is a common practise in the rice scheme may have reduced organic N in the rice fields' soil.

The lowest TSS recorded at the outlet of the rice fields may be due to physical processes such as sedimentation and filtration. Rice is traditionally grown in ponded water which allows incoming suspended solids from irrigation water to settle (Yoon, 2009). Moreover, rice plants reduce water velocity during tillering phase which increases plants density and hence promotes sedimentation (Forés and Comín, 1992). Filtration of sediments occurs when the stems of rice plants trap fine materials within their rough structures.

The low SRP and TP concentrations at the outlet of rice fields may be due to removal mechanisms such as adsorption to the soil, plant uptake, precipitation, filtration and sedimentation. Badhe *et al.* (2014) states that soluble P is bio-available and hence taken up by plants and bacteria and incorporated into biomass or adsorbed to soil. Insoluble form of phosphorus is primarily removed under aerobic conditions by adsorption into soil and precipitation with iron, calcium and aluminium (Yoon, 2009). Moreover, P precipitates with calcium when the pH is alkaline. Therefore, insoluble P in the rice fields may have been removed through adsorption into the soil due to presence of oxygen at the outlet, that is, 4.1mg/l and precipitation due to alkaline pH (7.2-9.4). The low concentration of TP at the outlet may also be due to sedimentation of suspended solids. According to Reddy *et al.* (1999) as suspended solids settle from the water column within the wetland, P bonded on soil particles is also removed.

Plants require nutrients for production of new cells during growth (Yoon *et al.*, 2003; Mugisha *et al.*, 2007). This makes availability and subsequent uptake of N and P which are usually limiting nutrients lead to increase in biomass production as noted in rice plants during the two consecutive harvesting during the growing period that is, 2.1kg DW/m^2 to 3.2kg DW/m^2. The increase in biomass as a result of nutrients uptake may explain the reduction in nutrients at the outlet as the rice grew.

The decline in TP and TN content in rice plants is in line with the findings of Mugisha *et al.* (2007) on nutrient uptake between young and mature macrophytes that indicated decline in nutrient content as the macrophytes age. Mugisha *et al.* (2007) states that young plants actively metabolize N and P resulting to more accumulation of the nutrients in plants as compared to mature plants. Moreover, nutrients are required in plants for development of new cells during growth and since at three and half months, rice plants have already matured, uptake may decline. Furthermore, as plants senesce nutrients is released back into soil and hence may explain the decline in nutrients content with age of rice plants (Hes *et al.*, 2014).

Overally, nutrients removed from rice fields through uptake and assimilation into biomass, exceeded fertilizer input of 23.5kgN/acre applied in the rice fields during the entire rice growing season. The output of TN of 217.7kgN/acre and TP 18.6kgP/acre indicated that rice plants were capable of taking up nutrients from the applied fertilizers, soils and irrigation water. Moreover, the nutrient output by rice plants still exceeded the inputs from fertilizer even when the plants were mature. This implies that rice plants may be the main output of nutrients in the rice fields.

5.7 Efficiency of natural wetlands and rice fields in retention of nutrients and TSS

Nutrients and TSS retention in natural wetlands and rice fields is important in reducing the loads to downstream aquatic ecosystems (Yoon *et al.*, 2003; Kyaw *et al.*, 2005; Kanyiginya *et al.*, 2010). In Ombeyi natural wetland, though no significant variation in TSS and nutrients concentration was observed at the inlet and outlet of the wetland, both nutrients and TSS were retained in minimal amounts. The nutrients retention; NH_4-N 25%, NO_3-N 19.6%,TN 19.1%,SRP 28.8%,TP 50% and TSS 45.5%, reported in this study are much lower than those reported in studies done by Kanyiginya *et al.* (2010) in Natete wetland in Uganda that indicated nitrate, ammonium, total nitrogen and SRP retention by 98%, 21%, 35% and 72% respectively. Furthermore, Adhiambo (2013) reported SRP retention of 61.8%, NH_4 -N 31%, NO_3-N 32.7%, TP 57.4% and TN 31%.

The high ammonium retention (25%) in the natural wetland compared to nitrate (19.6%) and TN (19.1%) retention may be attributed the negative correlation between ammonium, nitrate and TN concentration at both inlet and outlet of the wetland. Ammonium is converted to nitrate in aerobic conditions through nitrification (Verhoeven *et al.*, 2006). Thus, in the wetland since there was oxygen concentration of approximately 3.8mg/l the high retention of ammonium in comparison to nitrate and TN may be due to nitrification. The high retention observed for TP and TSS concentration on the other hand may be due to settling of sediments at the outlet due to low water velocity of approximately $0.08m^3/s$ as compared to inlet's velocity of $0.11m^3/s$. Insoluble P is mainly removed through adsorption and sedimentation (Havens *et al.*, 2004; Hogan *et al.*, 2004). Therefore, as the sediments settle, the adsorbed P is also removed resulting to the high retention as observed in the wetland.

In rice fields, nitrate and TN were retained by 36.9% and TN 35.7% respectively. These results are comparable to the findings of Yoon *et al.* (2003) on nutrient mass balance in Korean rice fields that indicated TN retention of 41.9%. Furthermore, Kyaw *et al.* (2005) reported N retention of 16.8% (input of 298kgN/ha and output 248kgN/ha) in rice fields. Nonetheless, rice fields acted as source of ammonium during the first months of rice growth though the concentration was not significantly different from the inlet and drainage canal. The high TN and nitrate retention compared to ammonium may be attributed to low oxygen concentration at the outlet of rice fields resulting to ammonium accumulation at the site and limitation of nitrification. Furthermore, TN and nitrate were positively significantly correlated while ammonium, nitrate and TN were negatively correlated in rice fields.

The low SRP and TP concentrations at the outlet as compared to the inlet of rice fields were indications of retention. SRP was retained by 79.16% while TP 60.52%. These results agree with the findings from the work done by Forés and Comín (1992) on rice fields in Spain which had P retention of 75%. However, Yoon *et al.* (2003) reports a lower TP retention of 11.03% in rice fields in Korea. The TSS retention of 58.21% reported in this study was comparable to findings of Darma *et al.* (2011) in terraced paddy rice fields in Indonesia that indicated TSS retention of 37.3%. The high retention of SRP compared to TP may be due to uptake by rice plants as water passes through the rice fields, whereas the high retention of TP as compared to TSS may be attributed to both settling and adsorption of particulate P into sediments.

Water purification function of rice fields was reflected in the rice fields' drainage canal. Minimal concentrations of nutrients and TSS loadings into River Ombeyi through drainage canal were observed. Despite the rice fields being source of ammonium, the amount of ammonium loadings into River Ombeyi was very low. This may be attributed to high oxygen concentration (5.8mg/l) in the drainage canal and thus nitrification process oxidizing ammonium released from rice fields into nitrate. Consequently, high amounts of nitrate and TN were released into River Ombeyi. The low loading of SRP into the river on the other hand may be due to plant uptake as water passes through the rice fields while for TSS and TP sedimentation may have contributed to their low loads.

Generally, from the retention values observed in both Ombeyi natural wetland and rice fields, there is an indication of water purification as an ES of both systems. However, comparison of variables within the two sites in relation to amount of nutrients concentration retained, rice fields retained more nutrients compared to the natural wetland. This may be attributed to channelization of the river flowing through the wetland and thus limiting interactions between water and wetland biota.

CHAPTER SIX
CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Ombeyi natural wetland and rice fields provide varieties of ES which support livelihoods and well-being of the local community. Though these services are presently provided at different magnitudes by both systems, it is evident that conversion of the natural wetlands into rice fields has affected the supply of provisioning, water purification and partially cultural ES derived from the wetland. Rice fields on the other hand appear to provide more ES compared to the natural wetland. Water purification ES provision through nutrients and TSS retention is enhanced in rice fields. Moreover, provisioning ES derived from the rice fields exceeds the natural wetland's provisioning ES. However, the entire trade-offs between ES derived from the natural wetland and rice fields may not only directly affect community members who still rely on the ES from the wetland but also indirectly negatively impact the entire community. This is because the sustainability of the irrigation schemes coupled with the future supply of ES derived from the rice fields are questionable without the natural wetland. Natural wetlands not only provide the ES assessed in this study but also other important ES for instance, water storage which is very important for both the irrigation scheme and also entire floodplain community through flood attenuation. Moreover, land disputes surrounding Ombeyi natural wetland which fuels more conversions into rice fields and other agricultural lands may lead to more losses than gains for the local community in regards to ES supplied by both systems. Therefore, sustainable utilization of both systems is important for synergies in ES provision in both systems since complete trade-offs also puts the future of the rice fields and their ES in jeopardy. In summary;

1. Provisioning, water purification and cultural ES have been negatively impacted by conversion of natural wetland into rice fields. Various provisioning and cultural ES in the natural wetland have declined as result of this conversion. Although rice fields seem to generate more income to the floodplain community this could be due to loss of other ES which would be provided by the natural wetland when performing to its maximum capacity if not degraded.
2. Natural wetlands retain significantly lesser nutrients and TSS compared to rice fields except ammonium where natural wetlands and rice fields showed no significant difference. In addition, the research concludes that rice fields are sources of ammonium while natural wetlands are transformers.

6.2 Recommendations

1. Cultural ES such as ecotourism and educational excursions in both systems should be promoted in collaboration with the local community. This will assist in reducing the pressure of conversions of natural wetlands into agricultural land to enhance income generation to the community. This can be achieved through establishment of tourism association among the communities to oversee marketing of products generated from the natural wetland.
2. In regards to water purification in rice fields, leakages of water containing high nutrients obtained in this study from rice fields during fertilizer application should be avoided by completely sealing the outlets of the rice fields. Alternatively, the drainage canals should be allowed to be inhabited by macrophytes to enhance water purification from rice fields before being discharged in the river as opposed to the recommendations of clearing the canals to farmers by NIB. This study recommends use of free floating macrophytes such as *Pistia stratiotes* in the drainage canals since it less invasive compared to other floating macrophytes and also cannot be used by birds for perching as in the case of emergent macrophytes (minimising crop damage).
3. The ES provided by wetlands should be recognized in management plans of Nyando floodplain in order to prevent further degradation of the wetlands functions and consequently reduction of their services and crop growing sustainability.
4. More studies should be conducted which cover other ES provided by both systems in order to make both environmentally and economically sound decisions on trade-offs between maximizing food production in rice fields and other ES derived from the natural wetland.

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APPENDICES

QUESTIONNAIRE

FIRST SET OF QUESTIONNAIRE SURVEY

Appendix 1: Ombeyi natural wetland ES

Table 1: Background information

Name of enumerator	
Phone number of enumerator	
Interview date	
Name of respondent/farmer	

A) Wetland Ecosystem Services

1. Do you and your household members derive or harvest any natural product (fish, macrophytes, wild game etc) from the wetland? Yes or No ________________

(a) If yes, then give details below;

Table 2: Products derived/harvested from the wetland

Natural products	**Name**	**Use**
Fish		
Vegetation (macrophytes)		
Wild game		
Others		

(b)If no, give reasons;

____

____

2. (a) Has there been any change in the delivery of natural products by the wetland as a result of conversion into rice fields and irrigation developments? Yes or No________________

(b) If yes, give details below (tick where applicable);

Table 3: Products availability in Ombeyi natural wetland

Natural product	Increased availability/gained	No change	Decreased	Lost

3. (a) Are there any educational and training activities both formal and informal on the wetland in this area? Yes or No ___________________

(b) If yes, which ones?

4. Are there any religious or spiritual uses of the wetland by the local community? Yes or No_________________

(a) If yes, which ones?

5. (a) Are there any aesthetic value attached to the wetland by the local community? Yes or No________________

(b) If yes, which ones;

____

____

(b) If no, give reasons;

____

____

____

____

____

____

6. Is this wetland used for any recreational activity? Yes or No _________________

   (a) If yes, which ones?

____

____

____

____

____

____

7. Is this wetland used for tourism? Yes or No______________

   (a) If yes, list the ecotourism activities and attractions;

____

____

Appendix 2: Kore Irrigation Scheme ES

A) Farmer's particulars

Farmer's name: ____

Size of the rice field (acres):_____________________________________

B) Rice fields ecosystem services

1. (a) Do you derive or harvest any natural product or by-product (fish, rice, hulls and straws, etc) from the rice fields? Yes or No ________________

   (b) If yes, then give details below;

Table 4: Natural products and by products from rice fields

Products/by-products	**Name (only fish)**	**Use**
Fish		
Hulls		
Straws		
Others		

8. (a) Are there any educational and training activities both formal and informal on which the rice fields/rice irrigation schemes are used? Yes or No ___________________

(b)If yes, which ones?

____

____

____

____

____

____

9. (a) Are these rice fields used for recreational activities? Yes or No_______________

(b) If yes, which ones;

____

____

____

____

10. (a) Are there any religious or spiritual uses/values of these rice fields to the local community? Yes or No________________

(b)If yes, which ones?

____

____

11. (a)Are there any aesthetic value attached to this rice fields by the local community?

Yes or No_______________

(b)If yes, which ones?

12. (a) Are these rice fields used for ecotourism? Yes or No______________

(b)If yes, list the tourism activities and attractions;

SECOND SET OF QUESTIONNAIRE SURVEY

Table 1: Background information

Name of enumerator	
Phone number of enumerator	
Interview date	
Name of respondent/farmer	

Appendix 3: Ombeyi natural wetland ES

1. (a) Do you and your household members derive or harvest any natural product (fish, macrophytes, wild game etc) from the wetland? Yes or No ________________

   (b) If yes, give details below;

Table 2: Natural products harvested, quantity, price and number of days harvested (if applicable)

Natural products harvested	Quantity (e.g. no. of mats, no. of fish)	No. of days harvested in a week	Price per unit (KES)
Fish			
Reeds			
Papyrus			
Grass (*Cyperus imensis*)			

   (c) Are there wild games used as food in this wetland? Yes or No? ________________

   (d) If yes, in a scale of 1-5 (0-1=high, 2-3=medium, 4-5=low) how would you rate their availability_________________

2. (a) When comparing wetland products provision now and 20 years back, is there any change? Yes or No________________

   (c) Give details below (tick where applicable);

Table 3: Natural products availability in Ombeyi natural wetland

Natural product	Increased availability	No change	Decreased	Lost
Fish				
Papyrus				
Reeds				
Grass				

3. (a) Are there any religious or spiritual uses of the wetland by the local community? Yes or No ________________

   (b) If yes, in a scale of 1-5 (0-1=high, 2-3=medium, 4-5=low) how would you rate these uses? ____________

4. (a) Is there any aesthetic value attached to the wetland by the local community?

   Yes or No _______________

   (b) If yes, in a scale of 1-5 (0-1=high, 2-3=medium, 4-5=low) how would you rate these values to the community? _____________

   (b) If no, give reasons;

   ____

5. (a) Is this wetland used for tourism? Yes or No_____________

   (b) If yes, in a scale of 1-5 (0-1=high, 2-3=medium, 4-5=low) how would you rate the frequency of tourists coming to the wetland per year? ___________

6. (a) Is this wetland used for educational excursions/activities? Yes or No_______

   (b) If yes, in a scale of 1-5 (0-1=high, 2-3=medium, 4-5=low) how would you rate the number of educational excursions/activities to the wetland per year? ______________

7. (a) Are there any recreational uses of the wetland by the local community e.g. swimming in the river flowing into the wetland? Yes or No ____________

   (b) If yes, in a scale of 1-5 (0-1=high, 2-3=medium, 4-5=low) how would you rate these uses? ___________

Appendix 4: Kore Irrigation Scheme ES

Farmer's particulars

Name: ____________________________

Size of the rice field (acres):___________________________________

C) Rice fields ecosystem services

8. (a) Do you harvest rice and fish from the rice fields? Yes or No _______________

   (b) If yes, then give details below;

Table 4: ES from rice fields and their indicators of measurements

Products	No. of bags (rice) or fish harvested	Quantity of each bag (kg)	No. of days harvested in a week (only fish)	Price per unit
Rice				
Fish				

9. (a) Are there any religious or spiritual uses of the rice fields by the local community? Yes or No ________________

   (b) If yes, in a scale of 1-5 (0-1=high, 2-3=medium, 4-5=low) how would you rate these uses? ____________

10. (a) Is there any aesthetic value attached to the rice fields by the local community? Yes or No _______________

    (b) If yes, in a scale of 1-5 (0-1=high, 2-3=medium, 4-5=low) how would you rate these values to the community? _____________

    (c) If no give reasons__________________

11. (a) Are these rice fields used for tourism? Yes or No_____________

    (b) If yes, in a scale of 1-5 (0-1=high, 2-3=medium, 4-5=low) how would you rate the frequency of tourists coming to the rice fields/irrigation scheme per year?

    ____

12. (a) Are there any recreational uses e.g. swimming in the canals of the rice fields by the local community? Yes or No ____________

    (b) If yes, in a scale of 1-5 (0-1=high, 2-3=medium, 4-5=low) how would you rate these uses? ___________

13. (a) Are these rice fields used for educational excursions/activities? Yes or No_____________

    (b) If yes, in a scale of 1-5 (0-1=high, 2-3=medium, 4-5=low) how would you rate the number of educational excursions to the rice fields per year? ____________

Thank you for participating in this survey!!!!