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ASSESSMENT OF WASTEWATER TREATMENT EFFICIENCY OF A CONSTRUCTED WETLAND AT FINLAYS FLOWER FARM, KERICHO, 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 in part or whole for any award in any institution

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RECOMMENDATION

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

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I dedicate this work to my son Goodluck who sacrificed early paternal care for this work to be done, my daughter Lightness who missed my escort to school and my wife who took charge on my behalf.

ABSTRACT

An assessment of wastewater treatment efficiency of Chemirei constructed wetland (CW) at James Finlay's farm in Kericho was carried out from November 2014 to February 2015. Water samples were collected twice per month from seven sampling points (S1-S7) using acid cleaned bottles for analysis. *In situ* measurements of Dissolved Oxygen (DO), pH, EC and temperature were done using calibrated meters and probes. Wastewater inflow and outflow rates for each purification cell were obtained using the volumetric method. Macrophyte biomass was determined using harvest method. Hydraulic retention time (t) and loading rate (q) were determined using mean flow rate (Q), system volume (V) and wetted surface area (A). In the laboratory; SRP, TP, NH_4-N, NO_3-N, NO_2-N, TN, TSS, BOD and COD were determined using Standard Methods for Analysis of Water and Wastewater (APHA, 2004). Data were checked for normality and homogeneity of variance prior to parametric test. Analysis was done using IBM SPSS statistics 21 (USA) and comparison of means of different wastewater variables were performed using Analysis of Variance (ANOVA). Tukey HSD post hoc test was applied to separate means between the sampling sites where all statistical tests were considered significant at $p<0.05$ (95% confidence interval). The mean inflow rate was 37.91 ± 9.96 m^3 and outflow 12.31 ± 4.67 m^3 per day with HRT of 14 days and HLR of 0.23 m per day. The results showed mean removal efficiency of NH_4-N (98%), TP (93.6%), SRP (61.6%), NO_3-N (88.6%), TN (88.6%), TSS (98.1%), BOD (69.5%) and COD (57.2%). Macrophyte nitrogen accumulation was highest in *Fimbristylis complanata* with 57.70 gm^{-2} and biomass of 3085 ± 99.31 gm^{-2} while phosphorus accumulation was highest in *Cyperus alternifolius* at 7.29 gm^{-2} with biomass of 8896 ± 195.61 gm per m^2. *Pistia stratiotes* had the lowest nitrogen accumulation at 3.73 gm^{-2} with biomass of 333 ± 18.59 gm^{-2} while *Cyperus rotundus* had the lowest phosphorus at 0.58 gm^{-2} with biomass of 503 ± 23.99 gm^{-2}. There was significant removal of nutrients and TSS ($p<0.05$) between the wetland inlet and outlet. This study found that there was no significant impact ($p>0.05$) on the receiving stream water at the point of effluent discharge with respect to nutrients and TSS. The constructed wetland was efficient in removing nutrients and TSS. However, it was not able to remove the COD to the required Kenyan effluent standard. The low removal rate is an indication of the presence of non-biodegradable compounds in the wastewater.

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LIST OF ABBREVIATIONS AND ACRONYMS

APHA	American Public Health Association
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CW	Constructed wetland
DO	Dissolved Oxygen
Dmm^{-2}	Dry mass per square metre
EC	Electrical Conductivity
FWS	Free Water Surface
HF	Horizontal Flow
HFCW	Horizontal Flow Constructed Wetland
HLR	Hydraulic Loading Rate
HRT	Hydraulic Retention Time
HSSF	Horizontal Sub-Surface Flow
IWA	International Water Association
OM	Operation and Maintenance
SRP	Soluble Reactive Phosphate
SF	Surface Flow
SSF	Sub-Surface Flow
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solid
VF	Vertical Flow
WW	Wastewater
WWT	Wastewater Treatment
N_2O	Nitrous Oxide
CO_2	Carbon Dioxide

CHAPTER ONE

INTRODUCTION

1.1 Background

Rapid increase in population growth and expansion of economic activities such as urbanization, industrial and agricultural growth are frequently associated with significant wastewater (WW) generation (Nzengy'a and Wishitemi, 2001), which requires effective treatment prior to disposal into the environment. The expanding floriculture in developing countries particularly in Kenya, with an enormous and increasing application of fertilizers and pesticides poses a potential threat to the environment, including aquatic ecosystems and human health through water pollution (Kivaisi, 2001) from both non-point and point sources.

In the last two decades, Kenya has turned into a successful cut flower exporter attaining the second largest developing country exporter in the world (English *et al.*, 2004). This industry has been valued as an economic achievement and earned an annual average of USD 141 million in foreign exchange (7 % of Kenyan export value) for the ten-year period (1996-2005) and about USD 352 million in 2005 (Mekonnen *et al.*, 2012). Despite the economic success, flower farms have been blamed for excessive water use, pollution and impacts on aquatic biodiversity (Kimani *et al.*, 2012; Mekonnen *et al.*, 2012).

The polluted water is frequently discharged into the aquatic environment (rivers and lakes) partially treated or untreated fostering eutrophication and dissolved oxygen depletion, leading to the death of aquatic organisms (Chen *et al.*, 2011; Saeed and Sun, 2012). Further, the situation is getting worse with rapid urbanization and agricultural growth coupled with continuing lack of proper sanitation in developing areas (Kivaisi, 2001). Increased use of fertilizer in agricultural activities contributes significantly to non-point source pollution through run-off. Ecological technologies such as constructed wetland (CW) for wastewater treatment (WWT) represent innovative and emerging solutions for environmental protection and restoration placing them in the overall context of the need for low cost and sustainable WWT systems in third world countries (Konnerup *et al.*, 2009; Vymazal, 2011; Nivala *et al.*, 2012). Constructed wetland is a potential system for treatment of agricultural wastewater due to their relatively low cost, low operation and maintenance requirements, and lack of reliance on machinery or energy inputs (Tanner *et al.*, 1995). Constructed wetlands have been applied in wastewater purification in many parts of the world and are highly suited to tropics due to favorable climatic conditions (Diemont, 2006).

Constructed wetlands treatment efficiency is a function of environmental conditions and proper management (Akratos and Tsihrintzis, 2007). In order to establish the efficiency of CW systems, various scientists have carried out studies on removal of pathogens, organic matter and nutrients (Kouki *et al.*, 2009; Saeed and Sun, 2012; Vymazal, 2013). Most of the research works done on CW efficiency have been carried out under temperate climate (Kaseva, 2004). To date limited research studies on the efficiencies of CW systems, particularly under tropical conditions in Africa have been reported (Kimani *et al.*, 2012) and even adoption and application of it has been unexpectedly low (Kivaisi, 2001). The need for long term monitoring to track efficiency trends especially in CWs treating flower farm wastewater is of urgent need since information is currently lacking. This study aimed at assessing wastewater treatment efficiency of a free water surface flow CW treating floriculture wastewater at Finlays flower farm located southwest of Kericho town in Kenya. The information generated will contribute to informed decision making in the management of the CW.

1.2 Statement of the Problem

Pollution of surface water impair aquatic ecosystem processes and pose ecological and public health risks in developing countries such as Kenya. This is due to population growth estimated in 2014 to be 2.11% and economic growth of 4.7% in 2013 contributing to discharge of untreated or partially treated WW into the environment. Agro-based industries in Kenya are rapidly growing with increased generation of wastewater to the aquatic environment. The use of CW is increasingly being applied in polishing such wastewater. The Finlays flower farm in Kericho employs hydroponic techniques in flower production creating nutrient loop and uses FWS CW to treat wastewater. Despite the use of CW in treating floriculture WW, treatment efficiency data is currently lacking. Constructed wetlands are not a "built and forget" technology and efficiency may reduce depending on management. Due to continuous operation over nine years now, it is important to track performance through periodic monitoring to ensure effectiveness and hence safeguard aquatic resources and public health from water pollution

1.3 Objectives

1.3.1 General objective

To assess wastewater treatment efficiency of a constructed wetland at Finlays flower farm, Kericho, Kenya.

1.3.2 Specific objectives

1. To determine hydrological and physico-chemical characteristics of FWS CW at Finlay's flower farm and water quality characteristics upstream and downstream of the point of treated WW discharge into the river
2. To determine above-ground biomass, nutrient sequestration and WW nutrients concentration effects on selected structural characteristics of macrophytes at Finlays constructed wetland
3. To assess temporal and spatial variation in treatment efficiency of Finlay's constructed wetland

1.4 Hypotheses

1. There is no significant difference in hydrological and physico-chemical characteristics among treatment cells and water quality upstream and downstream of the recipient stream.
2. There is no significant difference between structural characteristics of the macrophytes among the purification cells, above ground biomass and nutrient sequestration between different emergent macrophytes used in treatment wetland at Finlays constructed wetland.
3. Finlays constructed wetland is not efficient in wastewater treatment

1.5 Justification

The economic and social developments anticipated by Kenya Vision 2030 require healthier aquatic ecosystems and higher quality water supplies. The Constitution of Kenya 2010 under Article 42 provides a right to clean and healthy environment for every citizen. This includes the aquatic environment and its benefits. In addition, effluent dischargers are subject to stringent regulatory standards and are expected to adopt corporate social responsibility for clean environment; assuming responsibility for the effects of their actions and reporting action taken to protect the surrounding communities from adverse impacts of pollution. The Finlays' flower farm generate WW coming from different compartments but very often there is an assumption that such generated WW is rich in nutrients due to fertilizer application. The Finlay's farm has built FWS CW to treat WW before discharging into the environment. Currently, no comprehensive study has been conducted in this CW to assess the efficiency of the FWS system in treating the WW before discharging into aquatic environment. To date, monthly monitoring exists for a few selected parameters. However, it is important to carry out a more comprehensive study on the CW's performance so as to enhance maintenance and ensure continuous efficient performance.

CHAPTER TWO

LITERATURE REVIEW

2.1 Constructed wetlands characteristics and types

Constructed wetlands (CWs) are engineered or man-made WW purification systems that utilize biological, chemical and physical processes similar to processes taking place in natural wetlands (Lazareva and Pichler, 2010; Saeed and Sun, 2012; Sani *et al.*, 2013; Zhang *et al.*, 2014). Constructed wetland technology is amongst newly recognized green technologies for WWT (Abou-Elela *et al.*, 2013) in the tropics. This technology unlike conventional treatment requires less energy, low cost of OM and hence has a high potential for application in developing countries mainly by small remote communities (Kivaisi, 2001; Nivala *et al.*, 2012; Pozo-Morales *et al.*, 2014) and isolated industries which may not be connected to centralized WWT systems.

Constructed wetlands have been used for many years for municipal sewage treatment to reduce the concentration of nitrogen and phosphorus and lowering BOD (Dunbabin and Bowmer, 1992; Kouki *et al.*, 2009). In recent years, there has been increased use of CW for treating industrial and agricultural wastewater, landfill leachate or storm water runoff (Stottmeister *et al.*, 2003; Vymazal, 2005). Generally, CW have maintained high removal of pathogens, (Akratos and Tsihrintzis, 2007; Kouki *et al.*, 2009) toxic metals and organic pollutants (Belmont *et al.*, 2006) through microbial breakdown, assimilation by plants, adsorption, media filtration and biological predation (Saeed and Sun, 2011).

Constructed wetlands are categorized based on the type of vegetation dominating the system and hydrologic flow (Vymazal and Kröpfelová, 2008). Categorization by vegetation is based on the life forms such as emergent, free floating, floating-leaved and submerged (Kouki *et al.*, 2009) while hydrologic flow (Figure 1) are characterised by FWS and sub-surface flow (SSF) constructed wetlands (Zhang *et al.*, 2009).

Sub-surface flow CW is a shallow system with appropriate gravel bed where macrophytes are attached and allows continuous vertical or horizontal flows of WW below the surface of gravel through which is treated (Knowles *et al.*, 2011; Nivala *et al.*, 2012). It is normally designed to treat primary effluents before discharging into the environment or surface water (Kadlec and Wallace, 2009). Sub-surface flow (SSF) system allows WW to flow horizontally or vertically below the surface of gravel planted with wetland vegetation till the outlet area (Vymazal, 2005; Zhang *et al.*, 2009). A combination of HSSF and VF creates hybrid system to take advantage of maximizing WWT efficiency mainly through nitrogen removal (Vymazal, 2011). The hybrid system will get rid of organics, TSS and nitrogen through both nitrification (VF) and denitrification (HSSF) (Platzer, 1999; Zhang *et al.*, 2014).

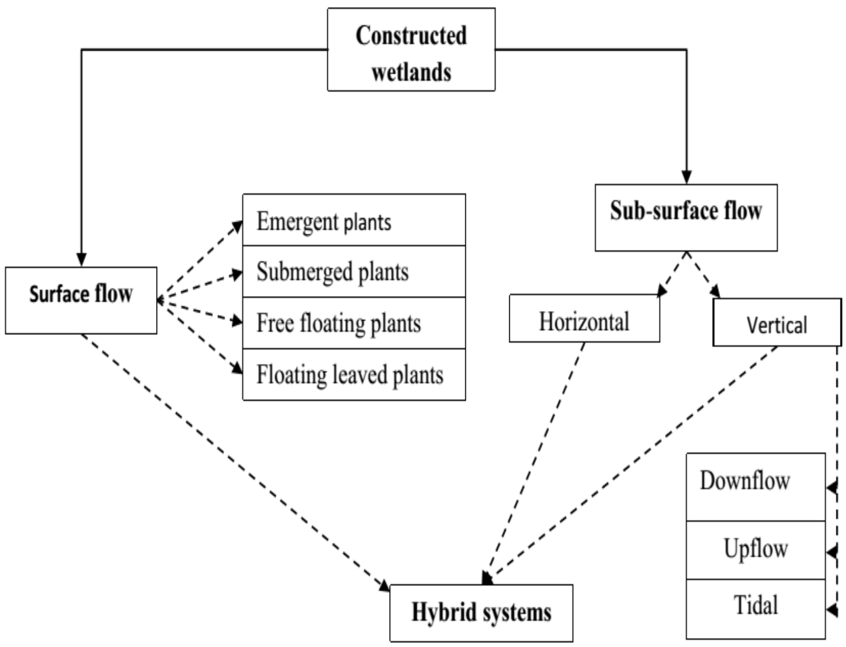

Figure 1: Classification of constructed wetlands for wastewater treatment (Vymazal and Kröpfelová, 2008)

Constructed wetlands have been designed and constructed to make use of natural processes involving wetland hydrology, vegetation and soils with associated microbial communities which assist in removal of pollutants through various biotic and abiotic processes (Vymazal, 2014; Xu *et al.*, 2014).

2.1.1 Hydrology and system design of constructed wetlands

Hydrologic variations such as renewal rate and frequency of water level fluctuations, influence the physico-chemical characteristics of CWs (Diemont, 2006). The variations influence soil characteristics and nutrient dynamics of the wetlands which in turn impact biota characteristics (Kadlec and Wallace, 2008). The performance of the CWs is highly dependent on creating and maintaining correct water depth and flows. Flow and storage capacity determine wetlands hydraulic retention time, providing opportunity for more interactions between the systems and wastewater (EPA, 1999).

Generally, system design has potential influence on pollutants removal process (Vymazal, 2010). In this study, emphasis will be in FWS constructed wetlands. Free water surface CWs refers to a designed and constructed system with open shallow water, soil or another suitable medium to support rooted vegetation and water often flows horizontally over the sediment (Gherimandi *et al.*, 2007; Kadlec and Wallace, 2009; Kouki *et al.*, 2009; Vymazal, 2014). Based on the location and soil conditions, berms, dikes and liners can be used to control flow and water loss through seepage. Free Water Surface wetlands are practically exceptional selection for WWT from urban, agricultural, industrial and storm waters due to their ability to deal with change in flow rate and water levels (Kadlec and Wallace, 2008).

This technology is not commonly in use currently compared to SSF CWs despite being one of the oldest system in Europe (Kadlec and Wallace, 2008; Vymazal and Kröpfelová, 2008) due to the large area requirement to optimize removal of pollutants. Free water surface CWs are classified based on the life form of macrophytes including emergent, free floating, floating-leaved and submerged (Kouki *et al.*, 2009).

2.1.2 Vegetation in constructed wetlands

The existence of macrophytes is a key prominent features of CWs which make them different from other treatment systems (Vymazal, 2011). Vegetation plays an important role in CW on nutrients uptake (Akratos and Tsihrintzis, 2007). They also have a potential in removing heavy metals and other contaminants (Abou-Elela *et al.*, 2013). In addition aquatic macrophytes stabilize the substrate, increase pore spaces, aerates the system, distributes wastewater (Abou-Elela and Hellal, 2012) and insulate water during winter (Taylor *et al.*, 2011; Vymazal and Březinová, 2014). Macrophyte diversity is likely to impact on microbial community due to habitat modification and further enhances pollutants removal performance (Boven *et al.*, 2008).

Studies have shown that macrophytes can have a positive effect on nutrient removal not only through assimilation but serving as substrate for microbial biofilms (Brix, 1994).

Wetland vegetation also play a role as the main biological component of system. They not only assimilate contaminants directly into their tissues, but also act as catalysts for the removal process by creating rhizosphere environment and promoting a variety of biochemical reactions that enhance pollutants removal (Jenssen *et al.*, 1993). Vegetation supports higher treatment efficiency for organics and nutrients facilitated by oxygen transfer mechanisms from aerial parts to the roots (Vymazal, 2011). The efficiency of vegetation species are affected by growth rate, biomass accumulation, quality of wastewater and environmental adaptation (Brisson and Chazarenc, 2009).

Emergent macrophytes improve substrate stability through the roots holding it firmly reducing erosion and re-suspension of particles. Macrophyte shoots provide hydraulic resistance and foster sedimentation as the speed of water and turbulence are reduced (Dunbabin and Bowmer, 1992). Submerged, rooted floating and free floating macrophytes trap pollutants from the water column and allow slow settling to the wetland bed. They also provide additional surface area for microorganisms attachment and further decomposition of organic matter (Kivaisi, 2001; Konnerup *et al.*, 2009). Selection of the macrophytic species is crucial in optimizing contaminants removal efficiency. It is believed that, the use of polytypic species provides habitat for microbes and hydraulic resistance increasing pollutants removal efficiencies (Konnerup *et al.*, 2009; Vymazal, 2011).

2.1.3 Substrates characteristics in constructed wetland

The substrate variation influence performance of CWs by affecting species diversity and abundance, primary productivity, organic deposition and nutrient cycling (Diemont, 2006). Substrate is regarded as a key components of wetlands (natural and constructed) which provides surface area for attachment of macrophytes and microbial films.

Microbial communities together with the substrate, removes pollutants in wastewater such as organics, nutrients and heavy metals (Vymazal and Kröpfelová, 2008) through uptake and adsorption respectively. Substrate characteristics such as particles distribution, porosity, degree of irregularity and infiltration capacity are crucial factors influencing the bio-treatment systems (Stottmeister *et al.*, 2003). The materials used as a substrate in CW should have high porosity to avoid clogging and be locally available to minimize the cost of construction (Prochaska and Zouboulis, 2006). Selection of root bed media is very essential since CW treatment efficiency may vary depending on the type of substrate (Pant *et al.*, 2001; Akratos and Tsihrintzis, 2007).

2.1.4 Microbial communities in constructed wetlands

Microbes are involved to a larger extent in wetland biogeochemistry nutrient removal. They transform and mineralize nutrients and organic compounds as part of pollutant removal processes (Stottmeister *et al.*, 2003). Microbial activity is affected by availability of oxygen where wastewater is purified aerobically near the roots zones or at the water surface in FWS and anaerobically at the bottom. In FWS, attached and suspended microbial growth is responsible for the removal of soluble organic compounds which are decomposed aerobically in the water column as well as anaerobically in the litter layer near the bottom (Vymazal, 2014). Nitrogen transformation is a typical microbial process leading to nitrogen removal by microbial nitrification (aerobic) and denitrification (anaerobic) while plants uptake is of less important (Stottmeister *et al.*, 2003; Chang *et al.*, 2012; Wang *et al.*, 2013; Zhang *et al.*, 2014).

2.2 Floriculture wastewater characteristics

Floriculture refers to agribusiness dealing with farming of flowering and ornamental plants. It is a recent booming production sector in Kenya with many environmental concerns in relation to the expansion of floriculture particularly with pollution foot print. Floriculture activities produce waste of different characteristics ranging from liquid to solid, toxic and non-toxic and in effect require safe waste disposal through treatment. Floriculture activities often associated with use of pesticides and chemical fertilizers and disposal of waste materials which are likely to damage the environment. Flower farms use large quantities of fertilizer, pesticides and water in the production processes. They generate WW from pack house, fertigation and spray stations, sprayers shower rooms together with surface runoff as non-point sources (Breilh, 2012).

In most cases, the WW from floriculture is enriched with nitrogen due to fertilizer application which causes water pollution. A study done by Kimani *et al.* (2012) on WWT efficiency at the Homegrown flower farm Ltd near shores of Lake Naivasha, indicated discharged WW having 5.1 mg/l of total nitrogen. This may stimulate eutrophication, exhibited by excessive algal growth in water bodies and ultimately ecological imbalance. Pesticides (which include herbicides, insecticides, fungicides and others) can contaminate organisms, soil, water and vegetation.

Flower farms postharvest units utilize chlorine to control bacteria and fungi in cut flower handling and vase solutions (Joyce *et al.*, 1996). Compounds frequently used for chlorination consist of sodium hypochlorite, calcium hypochlorite and dichloroisocyanuric acid which also contaminate the surroundings including flowing water (Xie *et al.*, 2008). Empty chemical containers (fertilizers, pesticides) and their washing waters are the major spheres of concern in addition to other agricultural waste such as cut off crop parts, unused soil, and WW generated in the sector.

2.3 Pollutants removal / retention mechanisms in free water surface constructed wetlands

Constructed wetlands have been used for treating floriculture WW prior to release to aquatic environment. Pollutant removal efficiency varies significantly not only from system to system, but also along the treatment pathway within the same system. In FWS systems, WW flow horizontally on the surface of the wetlands substrate often vegetated with emergent macrophytes where pollutants are removed by interactions of natural processes (Brix, 1993). Various mechanisms contribute to contaminants removal in CWs includes physical and biochemical processes. Physico-chemical processes remove a large proportion of pollutants including BOD, nutrients, pathogens and fixation of phosphate by iron and aluminium in the soil filter (Brix, 1993; Stottmeister *et al.*, 2003).

Biological removal mechanisms include microbial uptake or transformations but these are limited in the case of phosphorus. Phosphorus removal is associated with filter properties of the media rather than biological mechanisms (Badhe *et al.*, 2014). Soluble reactive phosphate is mainly taken by plants and bacteria converted to tissue phosphorus or may become sorbed to wetland soil and sediments while particulate may settle and become trapped in the litter and floc layers on the wetland bed (Kadlec, 2005; Badhe *et al.*, 2014). The main phosphorus removal processes are sorption, precipitation, plant uptake (with subsequent harvest) and soil accretion (Akratos and Tsihrintzis, 2007). Soil accretion is the only non-saturable process which occurs in FWS CWs.

Nitrogen removal mechanisms occur through microbial transformation in the rhizosphere, assimilation by plants and living organisms, volatilization and cation exchange of ammonia (Brix, 1994). Nitrogen removal by microbes in FWS involves nitrification in open water due to oxygen availability and denitrification in litter materials at the bottom. Ammonia is oxidized by nitrifying bacteria in aerobic zones and nitrate converted to free nitrogen or N_2O in the anoxic zones by denitrifying bacteria (Vymazal, 2005; Vymazal and Kröpfelová, 2008).

Total suspended solids in FWS with emergent macrophytes are removed mainly through sedimentation, filtration, aggregation and surface adhesion (Vymazal, 2014). Sedimentation process occurs within the first few metres at the inlet of constructed wetlands (Pozo-Morales *et al.*, 2014). The largest and heaviest particles will primarily settle out in the inlet open water zone while lighter particles may only settle out after flowing into wetland vegetation.

Other pollutants removed in CW include pathogens and heavy metals. Pathogenic microorganisms are removed from the water column through sedimentation, predation, natural die-off and exposure to ultra-violet radiation (EPA, 1999; Gherimandi *et al.*, 2007). Inorganic pollutants including heavy metals are removed by other process occurring in wetlands such as plant uptake, formation of complexes and subsequent precipitation (Cheng *et al.*, 2002).

2.4 Treatment efficiency in free water surface constructed wetlands

A free water surface CW is a WW polishing system utilising wetland plants that support a wide range of physical, chemical and microbial process (EPA, 1999). The processes work independently or jointly to remove TSS, BOD, COD, nitrogen and phosphorus. FWS systems have been applied at different stages of WWT to treat WW from different sources with different characteristics or pollutants. Wastewater treatment efficiency in such system usually varies due to stage of treatment, system design and source of wastewater.

A tropical experiment done by Sohsalam *et al.* (2008) in mesocosm FWS CW in Thailand seafood WWT, observed that the average removal efficiencies varied between 91-99% for BOD5, 52-90% for TSS, 72-92% for TN and 72-77% for TP. In Western Kenya Bojcevska *et al.* (2007) researched on the use of a FWS CW in treating sugar factory wastewater and found average removal efficiencies for TP, NH_4-N and TSS varying between 21-29%, 22-44% and 64-76% respectively. Generally, nitrogen is most effectively removed in FWS CW compared to phosphorus, although removed continuously but at relatively slow rate (Vymazal, 2014).

2.5 Factors affecting treatment efficiency in constructed wetlands

Pollutant removal efficiency of CW is a function of many factors including CW design, type, WW characteristics, environmental factors, operation and maintenance (OM), hydraulic retention time (HRT), hydraulic loading rate (HLR), type of substrate and vegetation diversity (Brisson and Chazarenc, 2009; Kouki *et al.*, 2009; Vymazal, 2010). In order to optimize WWT, the present study will focus on HRT, HLR, environmental factors, hydrologic and influent wastewater characteristics and field observation on routine operation and maintenance.

2.5.1 Hydraulic retention time and loading rate

The hydraulic retention time (HRT) and WW contact with substrate and plants roots has significant effects on pollutant removal (Stottmeister *et al.*, 2003). The efficiency of CWs depends on hydraulic retention time, hydraulic loading rate, influent characteristics, the level of pre-treatment (Prochaska *et al.*, 2007; Vymazal, 2010). In most CW systems, nutrients removal optimization requires a longer HRT compared with that required for organic load removal (Lee *et al.*, 2009). Hence, insufficient HRT reduce pollutant removal efficiencies by affecting natural treatment processes.

Hydraulic loading rate (HLR) refers to the volume of WW applied per day over a surface area and affects CWs treatment efficiency through saturation of the removal surfaces (Kadlec, 2009). Low loading rate of organic pollutants supports oxidized environment and optimizes nutrient and organic pollutants removal. If the WW loading rate is higher than oxygen availability, the oxygen demanding processes and nitrogen transformation through nitrification will be suppressed (Mesquita *et al.,* 2013). In the contrary, reducing loading rate for the sake of maximizing WWT efficiency, implies large areas will be required to attain high pollutant removal (Chang *et al.,* 2012). Hydraulic loading rate therefore has a significant impact on the design and treatment efficiency of constructed wetlands (Weerakoon *et al.*, 2013).

2.5.2 Hydrologic and influent characteristics

Wetland hydrology play a key role in maintaining wetland structure and function through controlling water and nutrients availability and aerobic and anaerobic conditions in both soil and water column (EPA, 1999). Wetlands water level is always variable due to loss and gains through evapo-transipiration, seepage and precipitation. Water gains through precipitation and loss through seepage and evapotransipiration dilute and increase pollutants concentration respectively.

Wastewater characteristics such as pollutant concentration, hydraulic loading rate and pollutants characteristics impairs CWs removal efficiencies (Prochaska *et al.*, 2007; Garfí *et al.*, 2012). It is recommended that, wastewater should be pre-treated before being released to a biological treatment system (Prochaska *et al.*, 2007) to dilute it as sometimes it is impossible to achieve effluents standards due to influent concentration level. It has also observed that, the phosphorus removal capacity is affected by increased influent of phosphorus concentration and loading rate (Pant *et al.*, 2001). Therefore, wetlands design should consider the balance between hydrology and wastewater characteristics for better performance.

2.5.3 Temperature variation in constructed wetlands and effects on treatment performance

Climatic condition has been recognized as having potential to influence CWs efficiency in removing contaminants including suspended solids and organic load, nitrogen through nitrification at high loading rate, even during cold winters (Diemont, 2006).

In the tropics, temperatures remain fairly constant all over the year with diel variation greater than seasonal differences. This is anticipated to positively affect pollutant removal efficiency.

Garfí *et al.* (2012) demonstrated that, removal efficiency for pollutants was clearly higher in summer than winter season. However, nitrogen removal is more affected by season and temperature due to microbial transformation processes (Van de Moortel *et al.*, 2010).

2.5.4 Oxygen fluctuations in constructed wetlands

Oxygen availability in CWs control metabolic activity of microorganisms within root zone and play important role in oxidation of metals and removal efficiency by precipitation (Nivala *et al.*, 2013). Transfer and availability of oxygen is the main rate-limiting wetland process in pollutants removal. Free water surface treatment wetlands have aerated zone at the water surface and anoxic zones at the sediment (Vymazal, 2014). The active zone of CW is the root zone (or rhizosphere) where removal natural processes (physico-chemical and biological) take place supported by interactions of plants, microorganisms, soil and pollutants (Stottmeister *et al.*, 2003). Oxygen is supplied to free water surface constructed wetland by atmospheric diffusion and within water column by periphyton and algae (Kadlec *et al.*, 2000).

2.5.5 Operation and maintenance

The operation and maintenance of FWS CWs is much less demanding compared to mechanized treatment systems such conventional wastewater treatment processes. Regular OM of CWs is as important design issues in maximizing pollutant removal performance which include hydraulic and water depth control, inlet and outlet structure cleaning, vegetation management and removal of accumulated sediments (EPA, 1999). Excellent OM extends the life span and performance of CWs (Lee *et al.*, 2009). Operation flexibility is crucial to maintain hydraulic regime to avoid unintended operational drawbacks which impairs removal efficiency(Kadlec and Wallace, 2008).

Maintaining the required plant density and diversity is the most important aspect in operation and maintenance. Macrophytes often contribute to organic matter accumulation in the system (Alvareza and Becares, 2006). Under these conditions, harvesting is necessary for improving system performance by avoiding increased sediment layer in FWS system which reduce efficiency (Kirschner *et al.*, 2001). In resolving these operational challenges, frequent monitoring is essential for operation and maintenance to enhance continuous wetland performance.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

3.1.1 Flower farm and constructed wetland location

The James Finlay Limited is a global tea and flower company situated within Kericho County about 20 km West of Kericho town. The town has a population of 150,000 persons and is located 400 kilometers from Nairobi. Finlay tea and Flower Company operates a number of tea estates and flower farms in Kericho and has also invested in floriculture industry in Naivasha and the Mount Kenya region.

Finlays Flower company was established in 1989 on the site of historic tea plantation in Kenya's Rift Province as Flower farm I and later Flower farm II in 1999 (personal communication with Mary Opisa from Finlays flower farm). All together, the flower farms cover approximately eleven hectares within Kericho and Bureti Districts. The flower farms generate wastewater from the sprayers shower room, pack house, fertigation and spray stations. In order to meet environmental regulatory requirements, Finlays flower farms use constructed wetlands to treat the wastewater before discharging to the adjacent aquatic environment. The Finlays Chemirei flower farm use free water surface flow constructed wetland. The study site is at Flower farm II within Finlays tea estate at latitude 00^{o}23'39.6" and longitude 035^{o}18'44.6" in an area lying 2167 meters above mean sea level along the equator (Figure 2).

3.1.2 Climate at the study site

The climate of the study area is largely influenced by the North - South movement of the Inter-tropical Convergence Zone (ITCZ) modified by local orographic effects (Olang and Kundu, 2011).The area is within Kenya western highlands where tropical climate and distribution of the rainfall provides suitable weather conditions for tea production throughout the year. It is within the Kenyan rift valley dominated by mountain ranges with high rainfall although dry areas are found in valleys and basins (Mogaka, 2006). In terms of rainfall seasonality, the area can be classified as bimodal, with a long rainy season predominant between May and June and the short rainy season between September and November. The mean annual rainfall of about 1300 mm has been reported for normal years without climatic extremes and mean monthly ranging from 30 mm to over 120 mm (Mogaka, 2006). The area fall under varied altitude with maximum temperature range between 22 °C - 28 °C and minimum range of 10 °C - 13 °C with mean air temperature of about 17 - 20 °C. The annual average evapo-transipiration estimate is between 1.3 mm and 4.2 mm per day (FAO, 2009).

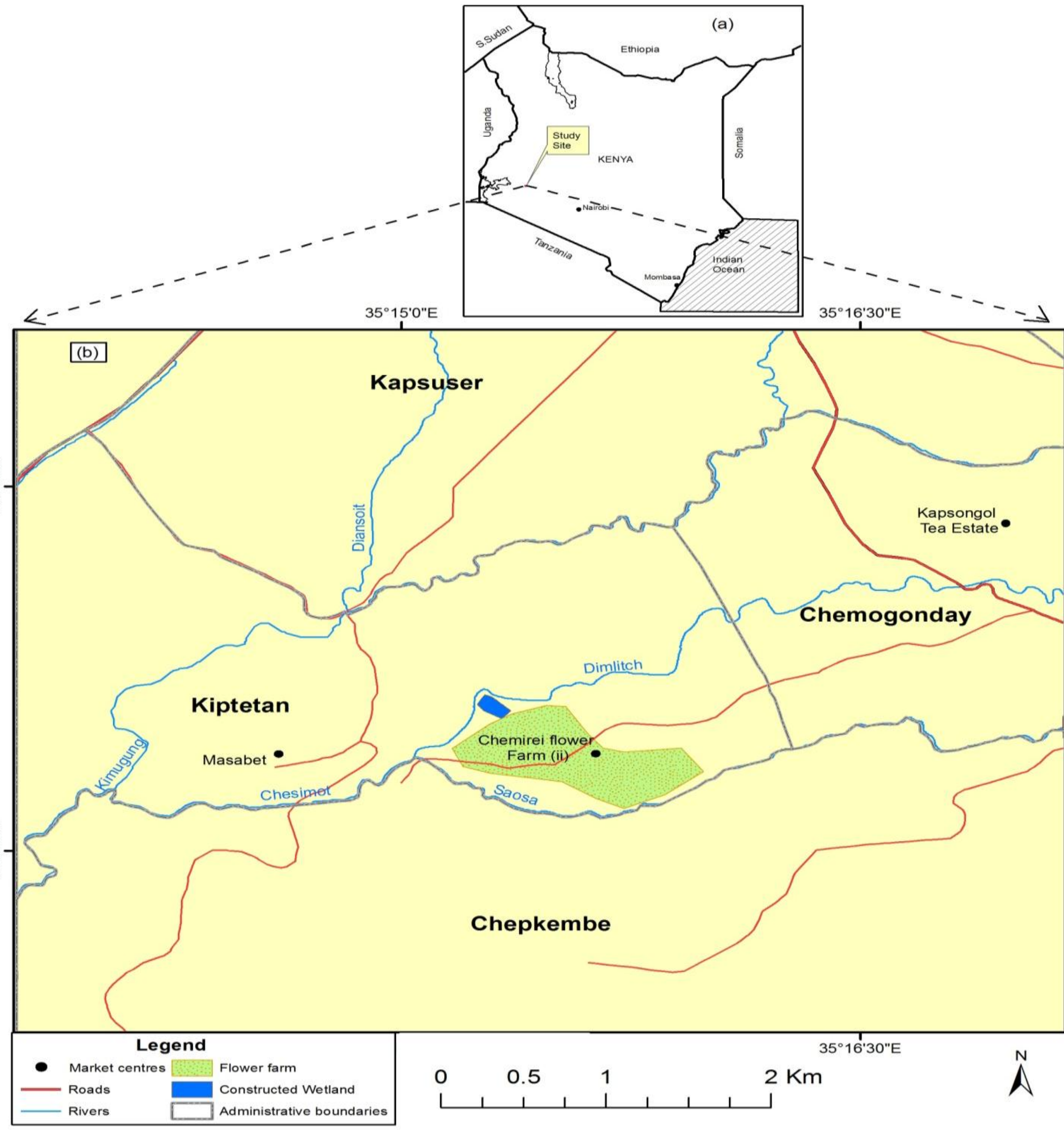

Figure 2**:** Map of Kenya showing location of the study site

Source: Topographic map of Kenya 1:50,000 (Survey of Kenya)

3.1.3 Finlay's constructed wetland

The constructed wetland is a free water surface flow type covering an area of about 4704 m^2 (1.2 acres). Chemirei constructed wetland was built in 2006 at Finlays flower farm II for the purpose of removing pollutants before discharging to the adjacent aquatic environment. The wetland is lined with clay soil to prevent wastewater seepage. One compartment in sedimentation chambers is lined with high density polythene liner to prevent loss of water through seepage. The wetland consists of three silt trap chambers and three irregularly shaped surface flow cells with variable dimensions and volume operated in series for removal of TSS and nutrients mainly phosphorus and nitrogen (Table 1 and Figure 3). The wetland was designed to receive approximately 30 m^3 per day of wastewater from sprayers shower room, pack house, fertigation and spray stations. The treated wastewater from the constructed wetland is discharged into the Dimlitch stream, one of the rivers within the Sondu Miriu system which drains into Lake Victoria.

Table 1: Finlay's free water surface constructed wetland cells dimension based on engineer's design

CW Section	**Length (m)**	**Width (m)**	**Depth (m)**	**Surface area (m^2)**	**Volume (m^3)**
Sediment trap	4.5	3.2	1.3	14.4	18.72
Surface cell 1	21.5	12	1.2	258	309.6
Surface cell 2	25	12	1.5	300	450
Surface cell 3	34	20	1.5	680	1020
Total				1252.4	1798.32

The dominant hydrophytes consist of twelve species of macrophytes (see appendix II); *Pistia stratiotes*, *Colocasia esculenta*, *Myriophyllum aquaticum*, *Canna australia*, *Sphaeranthus suaveolens*, *Potamogeton sp*, *Crassula aquaticum*, *Cyperus sp* and *Commelina sp* which contribute to nutrients removal and water quality improvement through plant uptake, filtration and sedimentation of suspended particles.

3.2 Sampling sites

Five sampling sites (S1-S5) were purposely chosen along the treatment pathway from the inlet to the outlet of FWS CW. To capture the potential effects of treated wastewater on recipient aquatic ecosystem, two sampling points (S6-S7) were included in the upstream and downstream of the discharge point into the river (Figure 3).

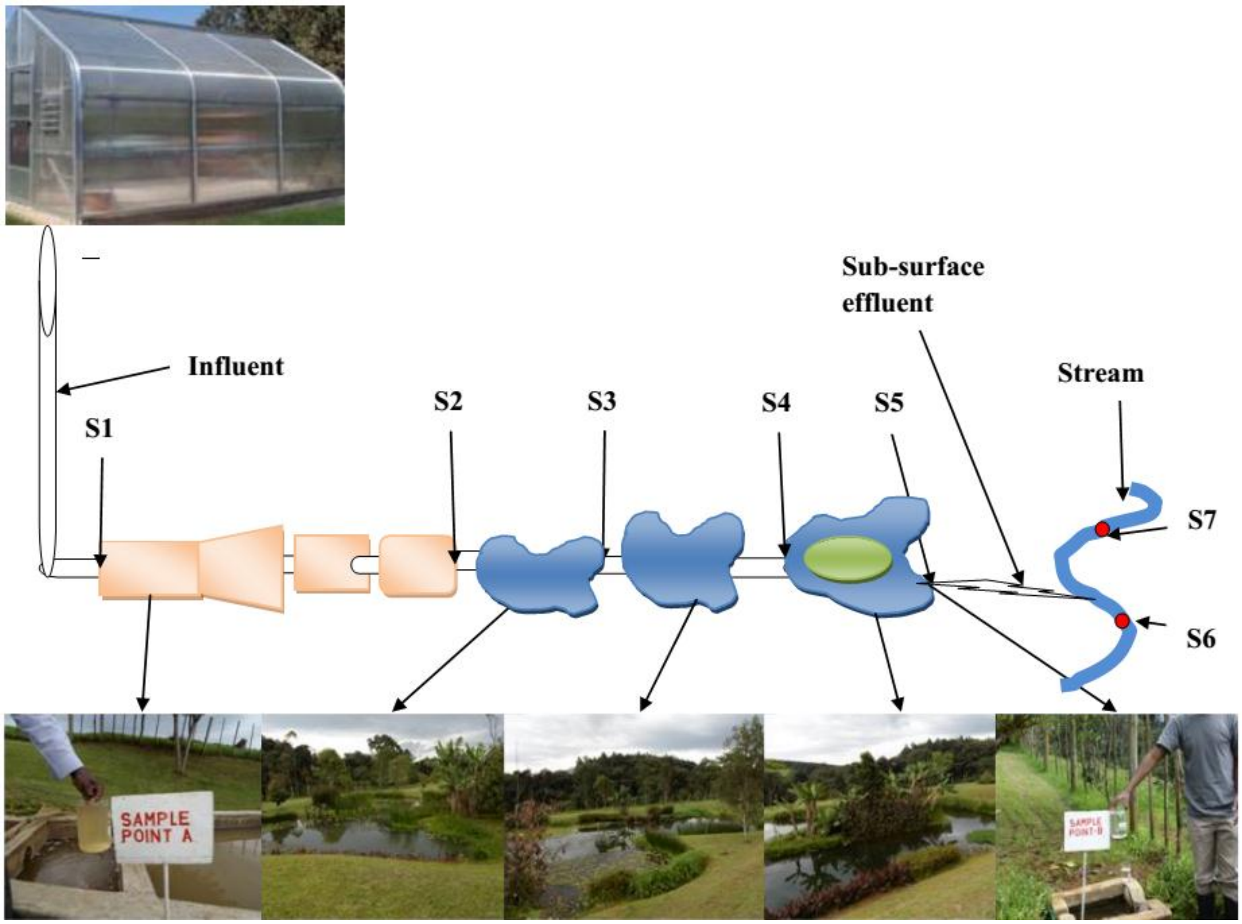

Figure 3: S1 - S7 represent sampling sites during the study period

Sampling site 1 (S1) is at the inlet of the CW receiving WW from the flower farm located in an elevated area almost 0.5 km from the wetland. Wastewater flows by gravity through plastic pipe of about 5 inches diameter to the wetland. This sampling site was chosen in order to capture the wastewater characteristics and it's volume from the flower farm into the CW. Sampling site 2 (S2) is the outlet of sedimentation compartment and inlet of purification cell 1. The outlet structure is designed to take water at the bottom of the compartment through upward flow to allow more suspended solids settling. Sampling site 3 (S3) is the outlet for cell 1 and inlet for cell 2 and surface water flows through a pipe pouring water to the next cell while allowing more aeration. Sampling site 4 (S4) is the outlet of cell 2 and inlet cell 3 with the same structure as the previous cell outlet and inlet. Sampling site 5 (S5) is the outlet of the last cell of the Finlays FWS CW discharging water through a v-notch into a vegetated channel. The water flows about 5 metres from the outlet and seeps through the soil down to the river. The river is about 250 metres from the outlet of the wetland with no distinct surface flow into the river especially during dry season. Sampling site 6 (S6) is about 100 metres upstream of the discharge point and sampling site 7 (S7) is about 200 metres downstream of the discharge point with respect to outlet of the wetland.

3.3 Sampling and field measurement

3.3.1 Field measurement

Surface area (A) of the irregular shaped surface purification cells and sedimentation chambers at Finlays FWS CW were determined with the aid of Garmin GPSmap 62s and tape measure using transect across the cells. Water depth of each cell was measured using eco-sounder in a designed transect across the cell. *In situ* measurements of temperature, pH, electrical conductivity (EC) and dissolved oxygen (DO) were determined at every sampling session using HACH HQ40d multi meter (HACH Co., Loveland, CO., USA). Previous and current weather data will be obtained from Chemirei flower farm II weather station which is located almost 0.5 kilometres from the study site. Selected structural characteristics of floating macrophytes (*Pistia stratiotes*) were assessed including fresh weight, leaves and roots lengths along the treatment pathway within purification cells (Cell 1 - Cell 3). Additionally, biomass density of emergent vegetation was assessed during the study period.

3.3.2 Water and plant samples collection

Wastewater samples were collected in duplicate in a clean acid rinsed 500 mls bottles after rinsing thrice with the site water. Samples were collected from each site twice per month from November, 2014 to February, 2015. A total of seven samples were collected each sampling session and transported to the Egerton University laboratory in ice-cooled boxes for analysis. Samples for dissolved nutrients (SRP, NH_4-N, NO_3-N and NO_2-N) were filtered using Whatman Glass Fibre Filters (0.45µm, GF/C) and analyzed immediately. For uncompleted analysis the samples were stored in refrigerator for analysis the following day. Above ground biomass for existing emergent and floating macrophytes were once harvested in triplicate at different purification cells in January 2015 for dry biomass and nutrient sequestration determination.

3.4 Water and plant sample analysis

Wastewater samples were collected and analyzed for SRP, TP, NH_4-N, NO_3-N, NO_2-N, TN, TSS, BOD and COD twice a month from November 2014 - February 2015. A standard calibration curves for each nutrient was prepared for sample concentration determination using standard procedures (APHA, 2004). Absorbance reading for each nutrient was done using GENESYS 10uv scanning spectrophotometer.

Macrophytes samples were oven dried at 70^oC for dry biomass per unit area determination (Kansiime and Nalubega, 1999). The dried samples were later ground, digested and used for determination of total nitrogen and phosphorus concentration using procedures outlined by Okalebo *et al.* (2002).

3.4.1 Determination of phosphorus in the water samples

Soluble reactive phosphorus was analyzed using ascorbic acid method (APHA, 2004) on the filtered samples. Reagents of ammonium molybdate (A), sulphuric acid (B), ascorbic acid (C) and potassium -antimonyltartrate-solutions (D) were prepared and mixed in the ratio: A:B:C:D = 2:5:2:1, (ml) where the order of mixing was very critical. Reagent mixture of about 2.5 ml was added to 25 ml of the sample and after 15 minutes, absorbance was read at 885 nm wavelength with distilled water as a blank. Total phosphorus was analyzed by first digesting and reducing the forms of phosphorus present in the unfiltered water sample into SRP using persulphate digestion. One ml of potassium persulphate was added to 25 ml of unfiltered sample and autoclaved for 90 minutes at about 120^oC. After digestion, SRP formed was analyzed using the ascorbic acid method (APHA, 2004).

3.4.2 Determination of nitrogen in the water samples

Ammonia-nitrogen was analyzed using sodium salicylate method (APHA, 2004) where reagents of sodium salicylate (A) and hypochloride solutions (B) were prepared. Reagent A amounting 2.5 ml was added to 25 ml of the sample with immediate addition of 2.5 ml of reagent B. The sample mixed with reagent was placed in the water bath at a temperature of 25ºC in the dark for 90 minutes after that, absorbance was read at 655nm wavelength for concentration determination. Nitrate (NO_3-N) was analyzed using sodium-salicylate method (APHA, 2004) where reagents of sodium-salicylate (A), concentrated sulphuric acid (B) and potassium-sodium tartrate solutions (C) were prepared and one ml of reagent A was added to 20 ml of filtered sample and left to evaporate overnight at 95ºC. The residue was dissolved using 1 ml of conc. H_2SO_4, followed by addition of 40 ml of distilled water and 7 ml of reagent C and absorbance read at 420 nm. Nitrite (NO_2-N) was analyzed using sulfanilamide method (APHA, 2004) where reagents of sulfanilamide (A) and N-naphthyl-(1)-ethylendiamin-dihydrochloride solutions (B) were prepared and one ml of reagent A was added followed by reagent B after 2 - 8 minutes to a 25 ml of filtered sample and absorbance read at 543nm wavelength.

Total nitrogen was analyzed by first carrying out persulphate digestion method (APHA, 2004) where all nitrogen forms were converted to ammonia. After the digestion, the resulting solution was tested for NH_4-N using sodium-salicylate method (APHA, 2004). The TN values were generated by adding up the concentration of NO_2 and NO_3 to the value of NH_4-N analyzed above.

3.4.3 Total Suspended Solids

The total suspended solids was estimated gravimetrically using glass-microfibre filter paper method (Whatman GF/C filters with pore size 0.45µm) (APHA, 2004). A known volume of WW sample was filtered using pre-weighed Whatman GF/C filter and then dried at 95ºC to a constant weight. The total suspended solids were estimated according to (APHA, 2004) formulae;

$$TSS\ (mgl^{-1}) = \left((Wc - Wf) * 10^6\right)V^{-1} \ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots \quad (1)$$

TSS Total suspended solids (mg l^{-1})

Wf Weight of pre-combusted filter in grams

Wc Constant weight of filter + residue in grams

V Volume of water sample used in ml

3.4.4 Biochemical Oxygen Demand (5 days) analysis (BOD_5)

Biochemical Oxygen Demand (5- days at 20°C) was analyzed using oxygen electrode method (Kruis, 2014) where oxygen concentration was measured by oxygen electrode immediately at the start of the experiment at the inlet and outlet of CW and after 5 days incubation. Additionally, upstream (S6) and downstream (S7) measurements of the BOD_5 were determined and compared with the BOD_5 of the effluent from the wetland. Initial oxygen concentration was measured onsite in the dark bottles and then covered with aluminum foil and kept in a dark place for five days at a temperature of 20°C. The final reading of oxygen concentration was measured after 5 days and BOD_5 calculated by the formula (APHA, 2004) ;

$$BOD\ (in\ mgl^{-1}) = \frac{So - Sv}{c} * Vs \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (2)$$

Where,

So DO sample, immediately at the start (mg/l)

Sv DO sample after 5 days (mg/l)

Vs Volume of sample bottle (ml)

C Volume of sample (ml)

3.4.5 Chemical Oxygen Demand analysis

Chemical oxygen demand was analyzed using closed reflux colorimetric method (APHA, 2004) through oxidation of organic matter by boiling mixture of chromic and sulphuric acids. Standard calibration curves for COD was prepared for sample concentration determination using standard procedures (APHA, 2004). Digestion solution mixture of H_2SO_4/Ag_2SO_4 and stock KHP were prepared. To a digestion tube 2.5 ml of unfiltered sample was added followed by 1.5 ml of digestion solution. Carefully, 3.5 ml of H_2SO_4/Ag_2SO_4 was run down inside the tube and acid layer was formed under the sample-digestion solution layer. The cap was tightened and the tube swirled several times to mix completely and then placed in pre-heated block at 150°C for 2 hours. The tube was cooled and the content mixed and the particles allowed to settle until the next day. The supernatant was transferred to a 1cm cuvette cell and absorbance read at 600 nm wavelength against water.

Correlation between BOD_5 and COD was determined by calculating the ratio between the BOD_5 and COD at inlet and outlet of the constructed wetland. This ratio is often used as an indicator for biodegradation capacity commonly known Biodegradability Index (B.I) (Metcalf and Eddy, 2003). It is a cut-off point between biodegradable and non-biodegradable WW and once established the COD test results can be used to compute the BOD_5 concentration.

3.4.6 Hydrological measurements

The volumetric method was used to check inflow and outflow rates at each purification cell at every sampling session. A measuring cylinder of the known volume and stop watch were used to measure the inflow and outflow rate of each cell ten times and average calculated. Hydraulic retention time (t) was determined by using mean flow rate (Q) and the system volume (V) by modified equation applied to wetland design in order to estimate the theoretical HRT (EPA, 2002).

$$t = \frac{Ad}{Q} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where,

t Theoretical HRT (days)

A Constructed wetland surface area (m^2)

d Water depth for FWS (m)

Q Average flow rate ($m^3\ d^{-1}$)

Hydraulic loading rate (q) was determined based on the measured wetted surface area of every purification cell and mean flow rate using Kadlec and Wallace (2008) equation. Hydraulic loading rate of every cell including the sedimentation chamber were determined separately and average calculated to get the overall loading rate of the constructed wetland

$$q = \frac{Q}{A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where

q Hydraulic loading rate (HLR), m d^{-1}

A Wetlands surface area (wetted land area), m^2

Q Average flow rate, $m^3\ d^{-1}$

3.4.7 Determination of above ground dry biomass and nutrients sequestration by the dominant macrophytes

Macrophytes were sampled once at the middle of the study period (January 2015) using 0.50 × 0.50 m square quadrat following Kansiime and Nalubega (1999). Three replicates were taken randomly for each species covering the three purification cells. The macrophytes were then harvested and transported to the Egerton University water quality laboratory. Each harvested quadrat was dried at 70^{o}C until constant weight for determination of above ground dry biomass. The biomass was calculated and expressed as dry weight in grams per square metre.

Nutrients allocation in above ground biomass for each macrophyte species were determined by analyzing percentage total nitrogen and phosphorus (see appendix I) from known weight of the dried ground sample by using digestion method (Okalebo *et al.*, 2002). The oven dry sample was ground using Universal hammer mill 9 FC-22A (Figure 4) to a powder form. Total nitrogen was analyzed by digesting 0.3g of the ground sample mixed with 4 ml of digestion mixture (conc. H_2SO_4 with selenium powder). 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 transferred in 100 mls volumetric flask and diluted with distilled water. Thereafter, 25 ml of diluted sample was added in the digestion tube and fixed in Kjeldahl distillation unit and 25 ml of 40% NaOH was dispensed. The samples were distilled by placing the conical at the receiving end of the distillation unit with 2% boric acid with mixed indicator (methyl red, bromocresol green dissolved in ethanol). Finally, 150 ml of the distillate green in colour was back titrated with 0.1M HCL as the colour turn from green through grey to pinkish at the end. The titration volume was used to calculate %N as follows (Okalebo *et al.*, 2002) ;

$$N\% = \frac{(Ts - Tb) * molarity\ of\ HCL * Eq.\ wt\ of\ N * DF * 100}{w\ *\ 1000} \dots\dots\dots\dots\dots (5)$$

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 (Okalebo *et al.*, 2002).

$$N(g\ m^{-2}) = N\% * Species\ biomass\ (g\ m^{-2}) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (6)$$

Phosphorus was analyzed using colorimetric method (Okalebo *et al.*, 2002) where reagents of Sulphuric acid, ammonium molybdate solution, Ascorbic acid and molybdate reagents were prepared. Standard calibration curve was prepared for sample concentration determination using standard procedures. One ml of the digested sample was added into a test tube followed by 4 ml of ascorbic acid solution and 3 ml of molybdate reagent and mixed well. The mixture was allowed to stand for 1 hour for the colour to develop fully. Absorbance was read at 880 nm wavelength for phosphorus concentration determination. The obtained P concentration per kg of dry weight was further used to calculate phosphorus accumulation per square metre in respect to the dry biomass (mg/kg) as per Okalebo *et al.* (2002).

$$P\ (g\ m^{-2}) = Species\ biomass\ (g\ m^{-2}) * \frac{P(mg)}{1000g * 1000} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . (7)$$

3.4.8 Floating macrophytes structural characteristics

Selected structures of floating macrophyte (*Pistia stratiotes*) were determined randomly in different purification cells along the treatment pathway. Fresh weight of the sampled plant from each cell was measured by digital scale while the leaves and roots lengths were measured using tape measure. Average fresh weight and length of leaves and roots were compared between different purification cells to check for variability.

3.4.9 Determination of the wastewater treatment efficiency

The overall level spatial efficiency of the CW in nutrients removal was calculated based on the comparison of inlet mean concentration versus outlet mean concentration by using efficiency formula by Kimani *et al.* (2012).

$$\%\ efficiency = \frac{(Inflow\ mean\ concentration - Outflow\ mean\ concentration)}{inflow\ mean\ concentration} * 100 \text{.............} (8)$$

3.5 Data management and analysis

Data was stored in Ms-Excel and checked for normality and homogeneity of variance prior to parametric test. Normality was checked by Kolmogorov-Smirnov test while homogeneity of variances by Levene test. The data for *in situ* measurement variables were normally distributed while TSS and physico-chemical variables were not normally distributed. Standardization of the values and log transformation was done for TSS and physico-chemical variables prior to parametric test. Descriptive statistics was used to generate averages, standard deviation and standard errors. The results are presented in tables, line graphs and bars using IBM SPSS statistics 21 (USA). The differences between mean values at different sampling sites were compared using ANOVA. Tukey HSD *post hoc* test was applied to separate means between the sampling sites. Biodegradability Index (B.I) for Finlays flower farm wastewater was determined by calculating the ratio of BOD to COD for the raw wastewater (inlet) and after biological treatment (outlet) and compared with other ratios of the selected wastewaters. The overall nutrients removal efficiency (%) was calculated based on the comparison of inlet versus outlet mean concentrations and the data were presented in both spatial and temporal scale. All statistical tests were considered significant at $p<0.05$ (95% confidence interval).

CHAPTER FOUR

RESULTS

4.1 Hydrologic and physico-chemical characteristics of Finlays flower farm CW and recipient stream

4.1.1 Weather characteristics at the study site

The weather data from Finlays flower farm II (study site) is presented in Figure 4 and Figure 5 for November 2013 to February 2015 to capture at least two years trends and possible effects of water inputs into the CW through precipitation during the study period (pattern bars in Figure 5). Based on the data from the farm weather station, the average annual rainfall of 2013 to 2014 was 1794.45 ± 196.65 mm per annum with the highest precipitation recorded in March 2014 (187.3 mm). The lowest precipitation occurred in January 2015 (1.5 mm) within the study period. The lowest annual average rainfall coincided with the study period. However, the results showed the rainfall range between 1.5 - 112 mm during the study period with highest in December 2014 and the lowest in January 2015. The average maximum temperature over the past one year in the study site was 27.3^{o}C while the minimum was 9.4^{o}C. During the study period temperature ranged between 23.9^{o}C - 26^{o}C (maximum) and 9.4^{o}C - 10^{o}C (minimum).

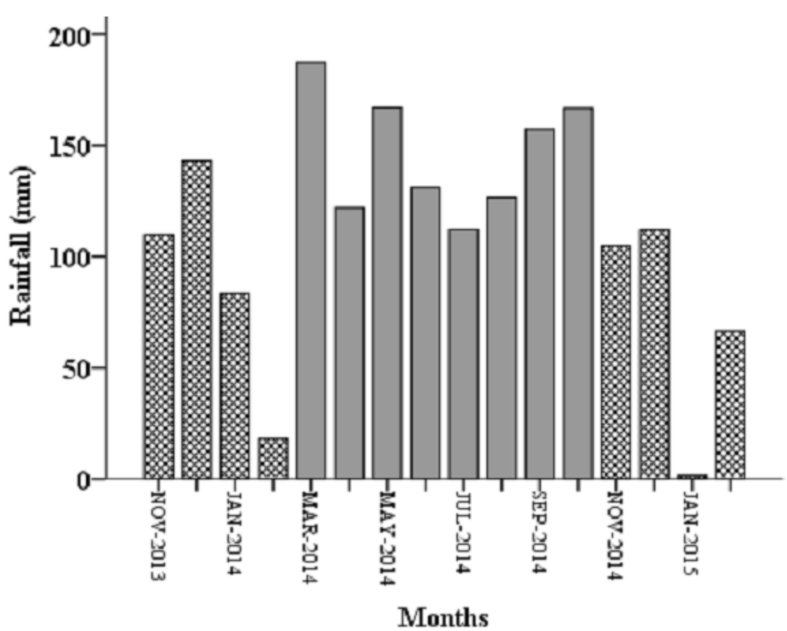

Figure 4: Monthly rainfall trends at the study site from November 2013 to February 2015 (Finlay's flower farm II weather station)

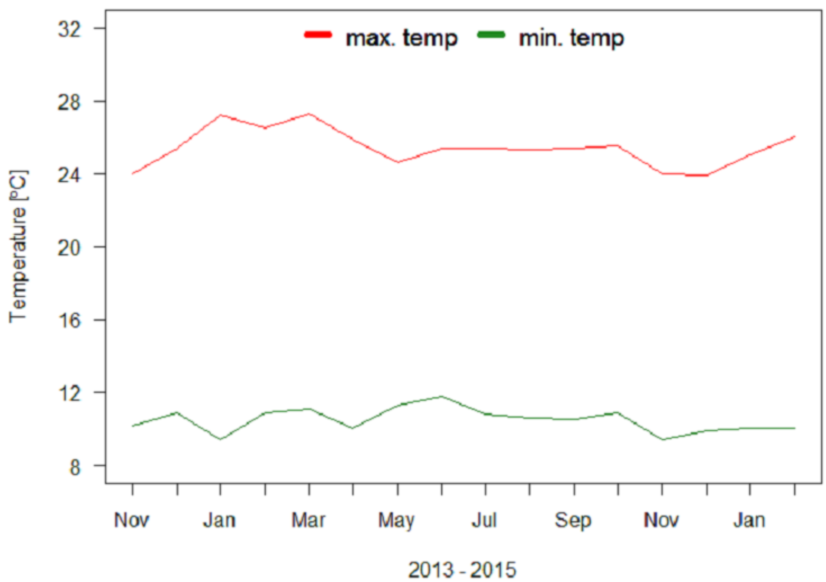

Figure 5: Maximum and minimum monthly temperature at the study site from November 2013 - February 2015 (Finlay's flower farm II weather station)

4.1.2 Size and hydrologic characteristics

Finlays free water surface (FWS) constructed wetland (CW) surveyed dimensions; discharge, HRT, HLR and daily mean flow variation are presented in Table 2 and Figure 4 below. The surface area and volume of the purification cells increases from the inlet to the outlet of the wetland but depth of the cells decreasing due to sediments accumulation. The total storage capacity of the wetland cells during study period was estimated to be 1049.6 m^3. The overall mean hydraulic retention time of the wetland was 14 days with loading rate of 0.23m per day. Hydraulic loading rate decreased along the treatment pathway among the wetland cells with increased retention time. The mean flow rate for the wetland at the inlet was 37.91±9.96 m^3 day^{-1} and 12.31 ± 4.67 $m^3 day^{-1}$ at the outlet during the study period. The constructed wetland had high variability in flow during the day and over time at the inlet as presented in Figure 4. The maximum inlet daily discharge of 11.7 l/min from the flower farm was recorded around 1100 hours with minimum of 3.1 l/min at 1800 hrs of the day. The maximum discharge at the outlet was 10.3 l/min with minimum value of 2.6 l/min obtained from monitoring period of two weeks (14 days) at both inlet and outlet as presented in Figure 6.

Table 2: Surveyed dimensions, HRT, HLR and daily mean flow rate for the Finlays free water surface CW (Data presented as mean ± SE)

FWS CW Section	**Area (m^2)**	**Volume (m^3)**	**HRT (days)**	**HLR (m/day)**	**Inflow (m^3 day^{-1})**	**Outflow (m^3 day^{-1})**
Sediment trap	53.20	79.80	2	0.75	37.91±9.96	42.41 ± 3.00
CW cell 1	330.42	231.29	7	0.1	42.41 ± 3.00	25.67 ± 2.56
CW cell 2	373.91	299.13	15	0.05	25.67 ± 2.56	15.26 ± 1.94
CW cell 3	488.14	439.33	32	0.03	15.26 ± 1.94	12.31 ± 4.67

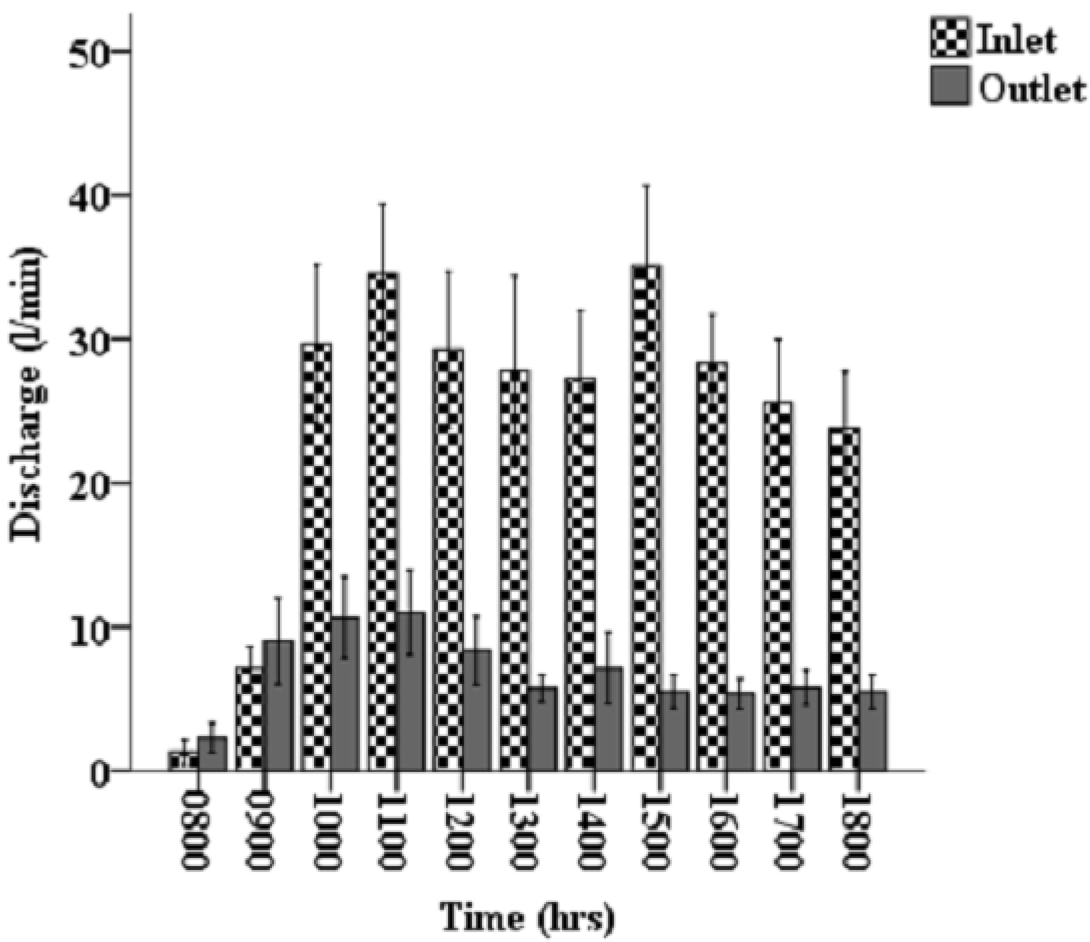

Figure 6: Daily flow variability at inlet and outlet of the Finlays FWS constructed wetland (n=14 days monitoring, values presented as means ± SE)

4.1.3 Dissolved oxygen, pH, conductivity and temperature

In situ characteristics of Finlays flower farm CW at influent, effluent, upstream and downstream of the discharge point to the river are presented in Table 3 below. During the study period, electrical conductivity (EC) varied significantly among sites (ANOVA, F = 42.958, d.f = 27, p=0.000). The mean EC ranged from 220.86 ± 12.38 μScm^{-1} at S1 to 97.25 ± 4.86 μScm^{-1} at S5. Post hoc analysis indicated significant variation between S1 and S5 (p=0.000) did not significantly vary between S6 and S7 (p=1.000). The mean concentration of dissolved oxygen (DO) varied significantly (ANOVA, F = 7.192, d.f = 27, p=0.001) between wetland and stream water but with no significant variation between S1 and S5 (Tukeys', HSD test, p=0.999). Variation of the DO between upstream and downstream was recorded with no significant difference (Tukeys', HSD test, p=1.000). The mean temperature also varied significantly at the study site (ANOVA, F = 15.851, d.f = 27, p=0.000) between S1 and S5 (Tukeys', HSD test, p=0.000) but no significant variation between S6 and S7 (Tukeys', HSD test, P = 0.978). The pH range (4.64 to 8.59) was recorded at the inlet with close range of within (6.13 - 7.64) recorded at outlet, upstream and downstream of discharge in the river.

4.1.4 Physico-chemical characteristics

The physico-chemical characteristics of wastewater at the Finlays flower farm CW inlet (S1), outlet (S5), upstream (S6) and downstream (S7) of discharge to the recipient stream are presented in Table 3, appendix III and its variability within a day in Figure 7. The mean concentration of ammonium-nitrogen (NH_4-N) varied significantly among the sites (ANOVA, F = 7.788, d.f = 43, p=0.000). Post hoc test revealed a significant difference between S1 and S5 (Tukeys', HSD test, p=0.011). The mean concentration of NH_4-N was observed with no significant difference between upstream and downstream of discharge into the river (Tukeys', HSD test, p>0.05).

Nitrate-nitrogen (NO_3-N) concentration varied significantly among the sites (ANOVA, F = 13.369, d.f = 43, p=0.000). Post hoc analysis indicated a significance difference between S1 and S5 (Tukeys', HSD test, p=0.000) with no significant variation between upstream and downstream of discharge into the river (Tukeys', HSD test, p=0.998). The mean concentration of the NO_3-N at the river water observed was 27.04 mg/l upstream and 25.89 mg/l downstream of discharge during the study period. A similar trend for the total - nitrogen (TN) was observed over the study period with significant difference among the sites (ANOVA, F = 14.722, d.f = 43, p=0.000). Post hoc test also indicated a significant difference between S1 and S5 (Tukeys', HSD test, (p=0.000) with no significant variation between S6 and S7 (Tukeys', HSD test, p=0.998).

The mean soluble reactive phosphate concentration among the sites did not vary significantly (ANOVA, F = 1.970, d.f = 43, p=0.134). Lower values of SRP were recorded at the sites. The mean total phosphorous (TP) varied significantly among the sites (ANOVA, F = 20.125, d.f = 43, p=0.000), where post hoc revealed a significant difference between S1 and S5 (p=0.000) with no significant difference between S6 and S7 (Tukeys', HSD test, p>0.05). The mean total suspended solids (TSS) among the sites varied significantly (ANOVA, F = 39.667, d.f = 43, p=0.000) with the highest values recorded at the S1 and the lowest at S5. Post hoc analysis indicated a significant variation between S1 and S5 (p=0.000) with no significant variation between S6 and S7 (p =0.948).

Table 3: Mean values of WW characteristics at Finlay's FWS CW, upstream and downstream of wastewater discharge into river (data presented as mean ± SE)

Parameters	**n**	**CW inlet (S1)**	**CW outlet (S5)**	**Upstream of discharge point (S6)**	**Downstream of discharge point (S7)**
EC (μScm^{-1})	46	220.86 ± 12.38^{a}	97.25 ± 4.86^{b}	46.53 ± 1.30^{b}	46.27 ± 1.56^{b}
DO (mgl^{-1})	46	5.45 ± 0.10^{a}	5.40 ± 0.50^{a}	7.15 ± 0.01^{b}	7.22 ± 0.08^{b}
Temperature ^{o}C	46	17.66 ± 0.49^{a}	22.4 ± 0.86^{b}	23.12 ± 0.08^{b}	22.50 ± 0.70^{b}
pH	45	4.64 - 8.59	6.13 - 6.88	6.36 - 7.53	6.36 - 7.64
NH_4-N (mgl^{-1})	57	0.94 ± 0.23^{a}	0.02 ± 0.01^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}
NO_3-N (mgl^{-1})	57	53.19 ± 12.28^{a}	6.09 ± 2.30^{b}	27.04 ± 1.50^{c}	25.89 ± 1.96^{c}
TN (mgl^{-1})	57	54.79 ± 12.22^{a}	6.27 ± 2.37^{b}	27.35 ± 1.50^{c}	26.18 ± 1.96^{c}
SRP (mgl^{-1})	57	$0.06 \pm 0.02^{n.s}$	$0.02 \pm 0.01^{n.s}$	$0.00 \pm 0.00^{n.s}$	$0.00 \pm 0.00^{n.s}$
TP (mgl^{-1})	57	0.52 ± 0.07^{a}	0.03 ± 0.01^{b}	0.02 ± 0.00^{b}	0.01 ± 0.00^{b}
TSS (mgl^{-1})	57	103.10 ± 24.56^{a}	2.01 ± 0.50^{b}	3.60 ± 0.58^{b}	5.07 ± 0.71^{b}
BOD_5 (mgl^{-1})	18	5.30 ± 0.09^{a}	1.62 ± 0.36^{b}	2.05 ± 0.07^{b}	1.01 ± 0.26^{b}
COD (mgl^{-1})	18	295.76 ± 34.60^{a}	126 ± 20.76^{b}	137 ± 15.69^{b}	117.57 ± 13.76^{b}

N.B. Means with the same superscript letter are not significantly different at p=0.05 level while with different letters indicates significant difference (Tukeys HSD test)

4.1.5 Biochemical and Chemical Oxygen Demand

The mean BOD_5 and COD characteristics of wastewater at Finlays Chemirei flower farm constructed wetland are presented in Table 3. Biochemical Oxygen Demand (5 days) varied significantly among sites (ANOVA, F = 18.185, d.f = 23, p=0.000). Post hoc analysis indicated a significant variation between S1 and S5 (p=0.000) but no significant difference (Tukeys', HSD test, p=0.363) between S6 and S7. There was a similar variation of mean COD with significant difference among sites as BOD (ANOVA, F = 9.111, d.f = 33, p=0.000). The Tukey's HSD test indicated significant variation (p=0.000) with no significant difference in COD values between S6 and S7 (p=0.910) in the two sites along the river.

4.1.6 Daily variation of inlet wastewater characteristics at Finlays constructed wetland

Variation of the physico-chemical variables at Finlays flower farm CW inlet was analyzed and presented in Figure 7. The inflow WW was observed with variation in the level of nutrients and TSS at different times of the day associated with floriculture production activities. Monitoring of the influents during the day revealed two close peaks in the morning and evening for NH_4-N concentration associated with post harvest and cleaning activities with 2.08 mg l^{-1} and 1.69 mg/l of NH_4-N respectively (Figure 7a). There was variability in mean NO_3-N and TN concentration during the day with a range of 9.32 mg/l (cleaning) to 20.39 mg/l (propagation) for NO_3-N and 12.30 mg/l (cleaning) up to 22.61 mg/l (propagation) for the total nitrogen (Figure 7b and c). The highest concentration of the SRP was recorded in the evening associated with cleaning activity with mean concentration of 0.12 mg/l SRP. The study recorded a daily range of 0.01 mg/l - 0.13 mg/ l associated with post-harvest and cleaning activities (Figure 7d). The mean TP attained its peak concentration at 1400 hrs associated with propagation activity with 0.28 mg/l with the lowest value of 0.07 mg/l at 0800 hrs during post-harvest activity (Figure 7e). However, high variability in TSS was observed during the day with a mean range of 22.83 mg/l to 306.92 mg/l associated with fertigation and propagation activities (Figure 7f).

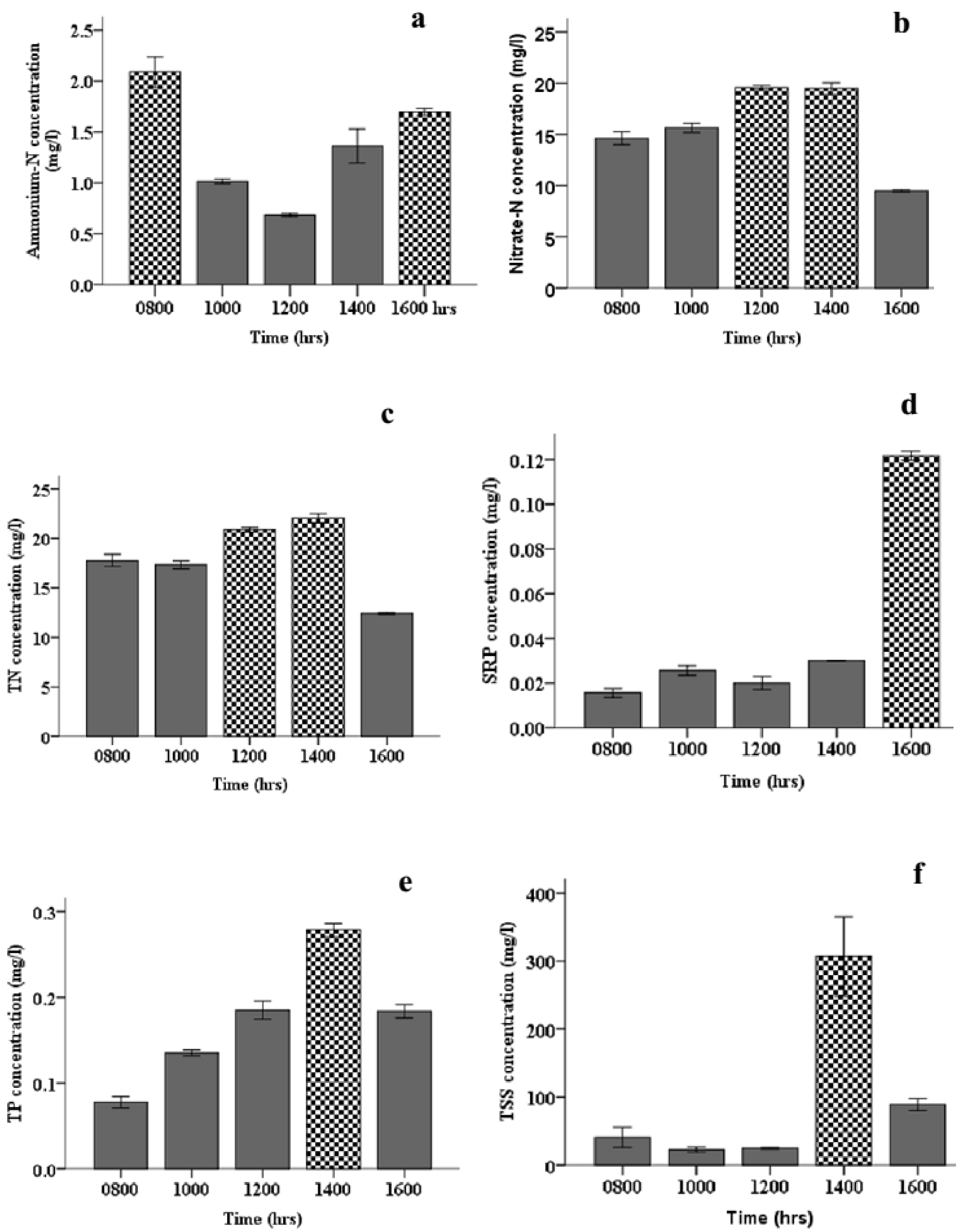

Figure 7: Constructed wetland inflow nutrients and TSS concentration variability associated with flower farm daily activities at Finlay's farm. (Values presented as means and SE, n = 15)

4.2 Spatial variation of physico-chemical variables at Finlay flower farm constructed wetland

The mean concentration (mg l^{-1}) and ranges for NH_4-N, NO_3-N, TN, SRP, TP and TSS with their variations along the CW treatment pathway are presented in Figure 8. Spatial variation of NH_4-N showed significant difference along the treatment pathway (ANOVA, F =5.645, d.f = 54, p=0.001, Figure 8a). There was significant difference in NH_4-N concentration between cell 2 and cell 3 of the CW (p=0.039). There was a similar trend in NO_3-N and TN concentration along the treatment pathway with significant differences obtained among different cells. Nitrate- nitrogen varied significantly (ANOVA, F =7.431, d.f = 54, p=0.000, Figure 8b) and post hoc test analysis indicated significant differences ($p<0.05$) between both inlet and cell 3 and from cell 3 with outlet of the Finlays CW. Total nitrogen concentration showed significant variation (ANOVA, F =8.242, d.f = 54, p=0.000, Figure 8c). Tukey's test revealed significant variation ($p<0.05$) in TN concentration between inlet compared with cell 2, 3 and outlet of the CW. Also, significant variation (Tukeys', HSD test, p=0.004) existed between cells 1 and 2 of the constructed wetland.

The mean concentration of SRP did not show any significant variation among the treatment cells (ANOVA, F = 2.263, d.f = 54, p=0.075, Figure 8d) and had generally low mean values from the inlet to the outlet. The mean concentration of TP showed significant variation along the treatment pathway (ANOVA, F =13.354, d.f = 54, p=0.000, Figure 8e) and Tukey's, HSD test revealed significant variation between S2, S3, S4 and S5.

The mean concentration of TSS significantly decreased along the treatment cells (ANOVA, F =31.841, d.f = 54, p=0.000, Figure 8f) with great reduction of suspended solids from the inlet to the outlet. The post hoc analysis indicated significant variation ($p<0.05$) of S1 to S2 which also varied significantly from the rest of the purification cells.

The mean concentration of BOD_5 and COD varied significantly ($p<0.05$, Table 3) from S1 to S5. Changes in both BOD_5 and COD concentration between inlet (S1) and outlet (S5) showed significant reduction (Tukeys', HSD test, p=0.000) of the amount of oxygen required for oxidation of organic matter. The observed mean concentration of COD ranged from 295.76 ±

34.60 mg l^{-1} at the inlet to 126.65 ± 20.76 mg l^{-1} at the outlet of the wetland. The BOD ranged from 5.30 ± 0.09 mg l^{-1} at the inlet to 1.62 ± 0.36 mg l^{-1} at the outlet of the wetland.

The mean values for EC, DO and temperature with their variations among the purification cells are presented in Table 4. A significant reduction in electrical conductivity (ANOVA, F = 34.057, d.f = 45, p=0.000) of flower farm WW was observed among purification cells. The post hoc test indicated significant variation ($p<0.05$) between S1, S3, S4 and S5. The mean dissolved oxygen concentration was observed with abrupt decline between S1 and S2 followed by sharp rise to a maximum level at S4 from where it remained relatively constant to the outlet. There was a significant variation (ANOVA, F = 19.954, d.f = 45, p=0.000) in DO among the purification cells. The post hoc analysis revealed no significant variation between S1 and S5 (Tukeys', HSD test, p=1.000) but showed significant difference ($p<0.05$) between S1, S2 and S3. The mean water temperature increased significantly (ANOVA, F = 12.705, d.f = 45, p=0.000) among the purification cells. The post hoc analysis revealed no significant variation of temperature (Tukeys', HSD test, p=0.380) between sedimentation chamber and surface cell 1 (S1-S2). However, significant variation was observed between S1 and S3, S4 and S5. The pH values ranged between 4.64 -8.59 at the inlet and 6.13 - 6.88 at the outlet of the constructed wetland.

Table 4: Spatial variation of the *in situ* measurements at Finlays flower farm constructed wetland during study period (Data presented as mean ± SE)

Parameter	**CW inlet**	**Surface cell 1**	**Surface cell 2**	**Surface cell 3**	**CW outlet**
EC (µScm^{-1})	220.86 ± 12.38^{a}	190.45 ±12.36^{a}	118.21±2.06^{b}	105.29 ±3.05^{b}	97.25 ±13.75^{b}
DO (mgl^{-1})	5.45 ± 0.10^{a}	0.52 ± 0.21^{ab}	3.20 ± 0.62^{b}	5.66 ± 0.90^{bc}	5.40 ± 0.50^{bc}
Temp (^{o}C)	17.66 ± 0.49^{a}	19.17 ± 0.58^{a}	21.44 ± 0.64^{b}	22.11 ± 0.56^{b}	22.41 ± 0.86^{b}

N.B. Means with the same superscript letter are not significantly different at p=0.05 level while with different letters indicates significant difference (Tukeys HSD test, n = 46).

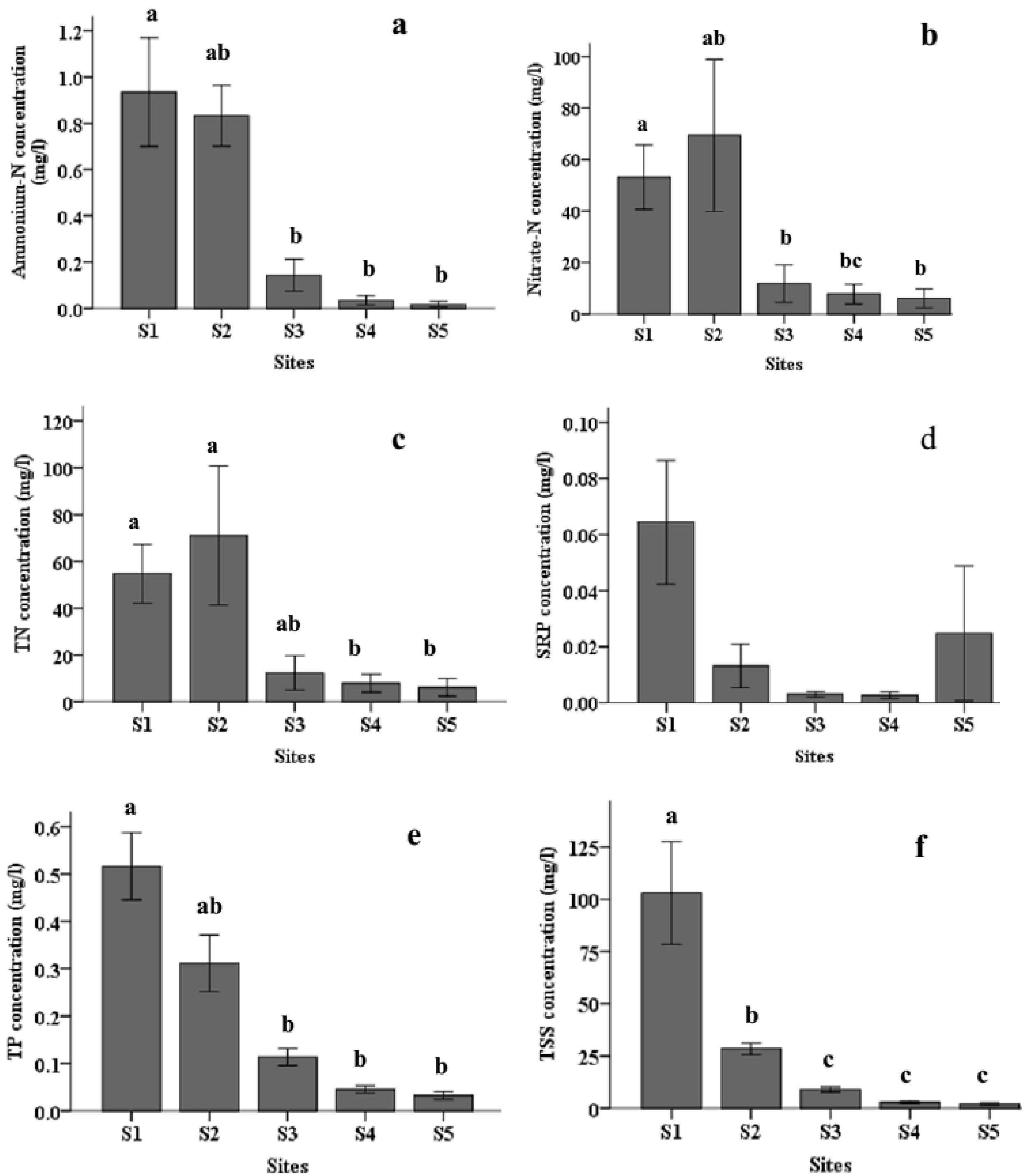

Figure 8: Spatial variability (S1-S5) of nutrients concentration and suspended solids at Finlays FWS CW (values presented as means ± SE, n = 57). Bars with the same letters are not significant different (Tukey HSD *post hoc* test)

4.3 Macrophyte biomass, nutrient accumulation and structural characteristics

4.3.1 Macrophyte standing biomass

The macrophytes biomass densities for the different species at Finlay's FWS CW are presented in Table 4. The highest biomass was found in *Cyperus alternifolius* with dry weight of 8896 ± 195.61 gm^{-2} while the lowest was in *Pistia stratiotes* with dry weight of 333 ± 18.56 gm^{-2}. Emergent macrophyte species had a greater biomass than floating species (Table 4).

4.3.2 Macrophyte nutrient accumulation at Finlays constructed wetland

The nutrients accumulation in above ground biomass of macrophyte species at Finlay's FWS CW are presented in Table 5 and appendix I. Nitrogen accumulation was in the range of 3.73 g m^{-2} - 57.70 g m^{-2} while phosphorus accumulation was 0.58 g m^{-2} - 7.29 g m^{-2}. Nitrogen accumulation was higher in *Fimbristylis complanata* (57.70 g m^{-2}) and lowest in *Pistia* stratiotes (3.73 g m^{-2}). The highest phosphorus accumulation was recorded in *Cyperus alternifolius* at 7.29 g m^{-2} while the lowest was in *Cyperus rotundus* (0.58 g m^{-2}).

Table 5: Above ground dry biomass and nutrient accumulation for macrophytes at Finlays FWS constructed wetland (Data presented as mean ± SE)

Macrophytes species	Dry biomass (g m^{-2})	Nutrients concentration in biomass (g m^{-2})	
		Nitrogen (g m^{-2})	Phosphorus (g m^{-2})
Cyperus rotundus	503 ± 23.99	6.58	0.58
Cyperus compactus	2471 ± 222.45	32.37	2.95
Fimbristylis complanata	3085 ± 99.31	57.70	3.58
Sphaeranthus suaveolens	1387 ± 50.53	23.30	1.99
Myriophyllum aquaticum	1068 ± 15.37	19.97	1.71
Cyperus haspan	1337 ± 28.29	19.93	2.56
Canna australia	1947 ± 23.13	47.30	5.65
Cyperus alternifolius	8896 ± 195.61	49.82	7.29
Cyperus latifolius	4081 ± 186.20	37.96	7.10
Crassula aquatica	549 ± 10.84	12.31	1.03
Zantedeschia aethiopica	1328 ± 31.13	19.79	6.52
Pistia stratiotes	333 ± 18.59	3.73	1.44

4.3.3 Structural characteristics of *Pistia stratiotes*

Selected structural characteristics including; fresh weight, root and leaf length of *Pistia stratiotes* along the treatment pathway (cell1 to 3) at Finlays FWS CW presented in Figure 9. However, the mean length of the leaves of *Pistia* did not show any significant variation among treatment purification cells (ANOVA, F = 2.707, d.f = 23, p=0.090, Figure 9a). The mean length of the *Pistia* roots varied significantly (ANOVA, F =56.372, d.f = 23, p=0.000, Figure 9b) among the treatment purification cells. The significant variations were recorded along three different purification cells. Post hoc test revealed significant difference between all the cells (Tukeys', HSD test, p<0.05). Mean fresh weight of the *Pistia* varied significantly (ANOVA, F = 7.491, d.f = 23, p=0.042, Figure 9c) among the treatment purification cells. The post hoc analysis indicated significant variation in plant features between surface cell 2 and 3 with no variation between cell 1 and the rest of the cells (Tukeys', HSD test, p=0.036).

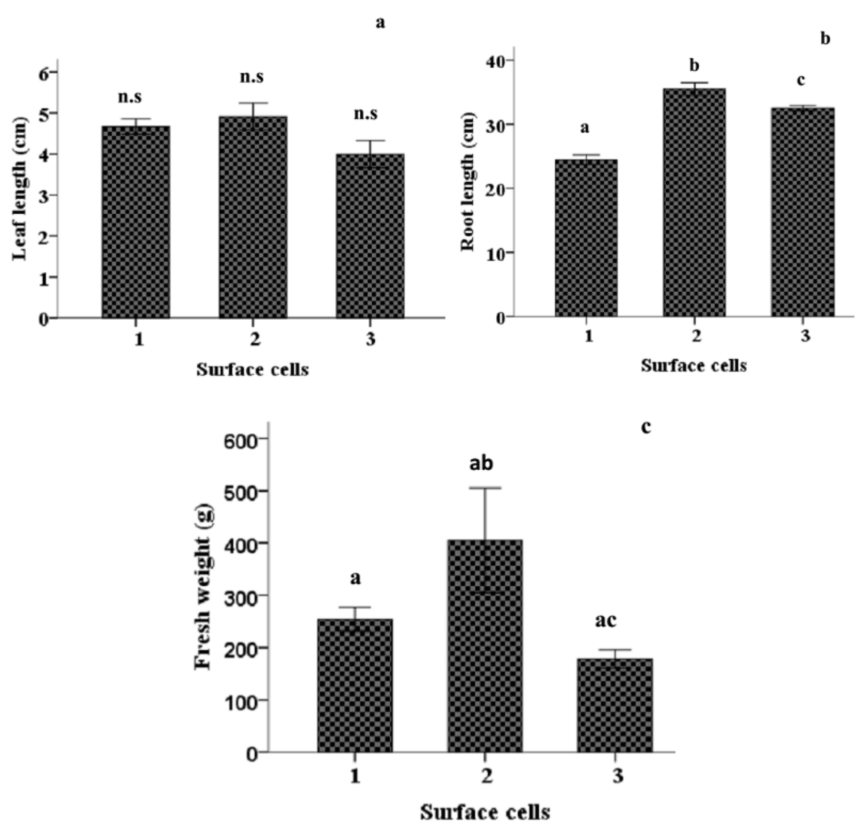

Figure 9: Comparison of *Pistia stratiotes* fresh weights, root and leaf lengths along the treatment pathway of Finlays constructed wetland (values presented as means ± SE, n = 24)

4.4 Temporal variation of physico-chemical variables at Finlays free water surface constructed wetland

The mean values for EC, DO and temperature with their variations among the sampling months / period are presented in Figure 10 (a-c). The mean EC at the inlet of CW over time did not change significantly during the study period (ANOVA, F = 0.114, d.f = 7, p=0.947, Figure 10a). The outlet mean EC also did not change significantly among the sampling months (ANOVA, F = 3.715, d.f = 7, p=0.119). During study period the mean EC maintained high values at the inlet ranging between 125.40 - 281.67 μScm^{-1} and lower values at the outlet within the range of 77.10 -119.50 μScm^{-1}. The mean DO at the inlet of the CW (4.64 - 5.8 mg/l) had no significant variation over the study period (ANOVA, F = 5.105, d.f = 7, p=0.075, Figure 10b). There was a similar trend at the outlet of CW (DO range 3.35 - 7.17 mg/l) with no significance difference during the sampling months (ANOVA, F = 0.625, d.f = 7, p=0.635). A comparison of mean temperatures at the inlet (15.53 - 21.23 ^{o}C) and outlet (19.10 - 23.50 ^{o}C) did not show a significant change both at the inlet (ANOVA, F = 1.592, d.f = 7, p=0.324, Figure 10c) and the outlet of the wetland (ANOVA, F = 3.262, d.f = 7, p=0.142) in the different sampling session at the Finlays constructed wetland.

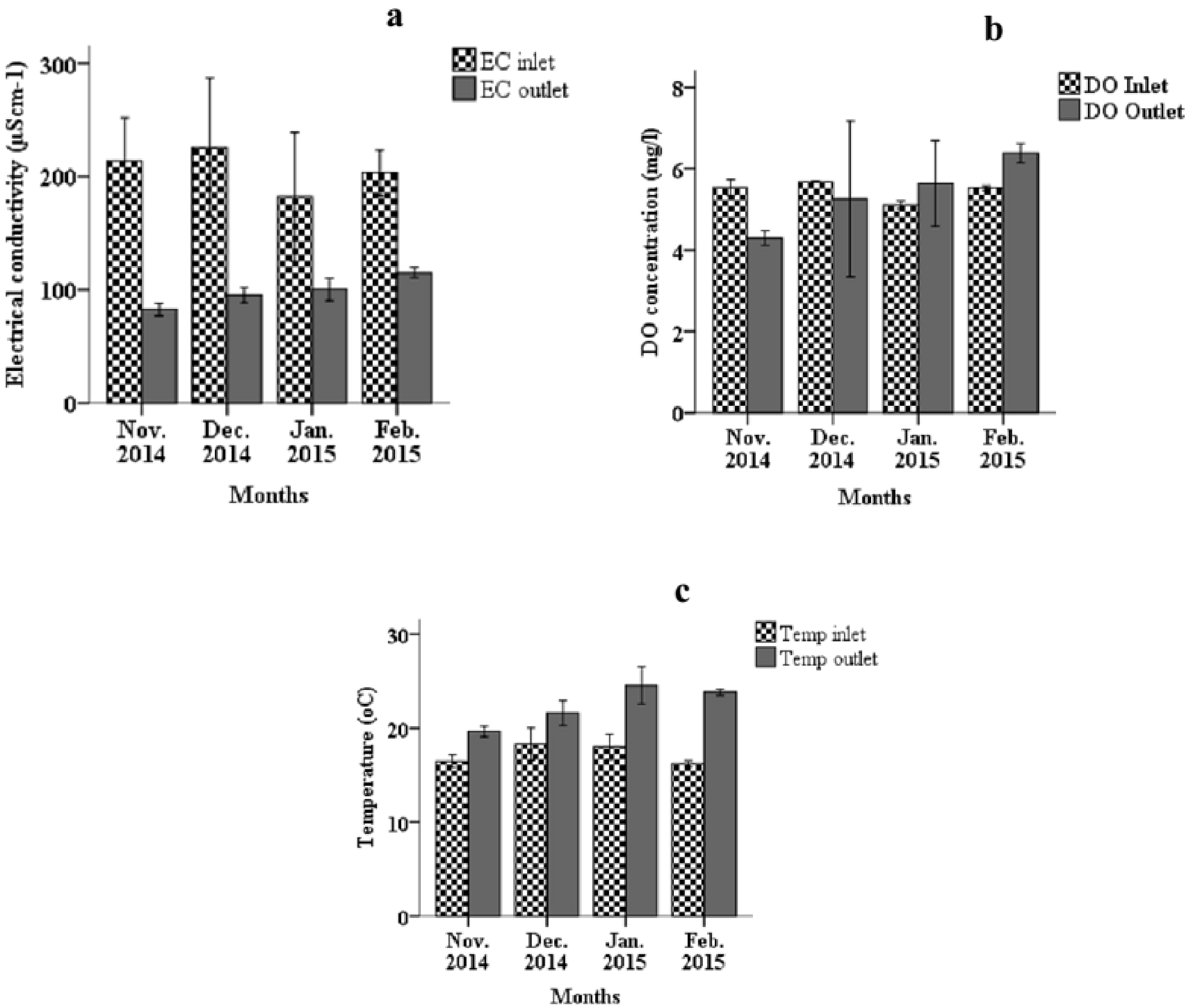

Figure 10: Temporal variability of *in situ* measurements of EC, DO and temperature at Finlays FWS constructed wetland (values presented as means ± SE, n = 8)

Results for variations over time (temporal) of the inlet and outlet physico-chemical variables during the study of November 2014 to February 2015 are presented in Figure 11 (a-f) NH_4-N concentration at the inlet did not differ significantly (ANOVA, F = 1.434, d.f = 8, p=0.337, Figure 11a) over time during study period. The same trend was observed in outlet NH_4-N concentration with no significant variation (F = 0.983, d.f = 8, p=0.471). The mean NO_3-N inlet concentration differed significantly during the sampling period (F = 22.058, d.f = 8, p=0.003, Figure 11b) but there was no significant variation (F = 1.735, d.f = 8, P=0.275) at the outlet of the constructed wetland over time. The post hoc analysis indicated significant increase in mean concentration of NO_3-N ($P<0.05$) in the inlet mean concentrations (83.47 mg/l and 124.21 mg/l) for December 2014 and January 2015 respectively. The outlet mean concentration of NO_3-N indicated no significant change among the sampling sessions (F = 1.735 d.f = 8, p=0.275). A similar trend was observed for the mean concentration of TN over time where inlet values differed significantly (F = 22.473 d.f = 8, p=0.002, Figure 11c) but without significant variation at the outlet (F = 1.785, d.f = 8, p=0.266). The post hoc test revealed significant increase ($P<0.05$) in mean concentrations of TN (85.18 mg/l and 125.26 mg/l) for the months of December 2014 and January 2015 respectively at the inlet of constructed wetland.

The inlet mean concentration of SRP did not differ significantly over the study period (F = 2.166 d.f = 8, p=0.211, Figure 11d). Soluble reactive phosphate was generally low over the entire study period. The outlet mean concentration of SRP also did not vary significantly (F = 1.280 d.f = 8, p=0.376). Concentration of TP over the study period at the inlet did not differ significantly (F = 1.020, d.f = 8, p=0.458, Figure 11e) over time. The same trend was observed in outlet TP (F = 0.205, d.f = 8, p=0.889).

A comparison of changes in TSS mean concentration at the inlet showed significant variation (ANOVA, F = 7.151, d.f = 8, p=0.029, Figure 11f) over time. The post hoc test indicated significant increase (P = 0.023) in TSS in the month of January 2015 up to 174.80 mg/l. The mean concentration of the TSS at the outlet did not vary significantly (ANOVA, F = 1.147, d.f = 8, p=0.416) with time. Despite the significant increase in the mean suspended solids concentration in the month of January 2015, the wetlands maintained low values of TSS at the outlet throughout the study period.

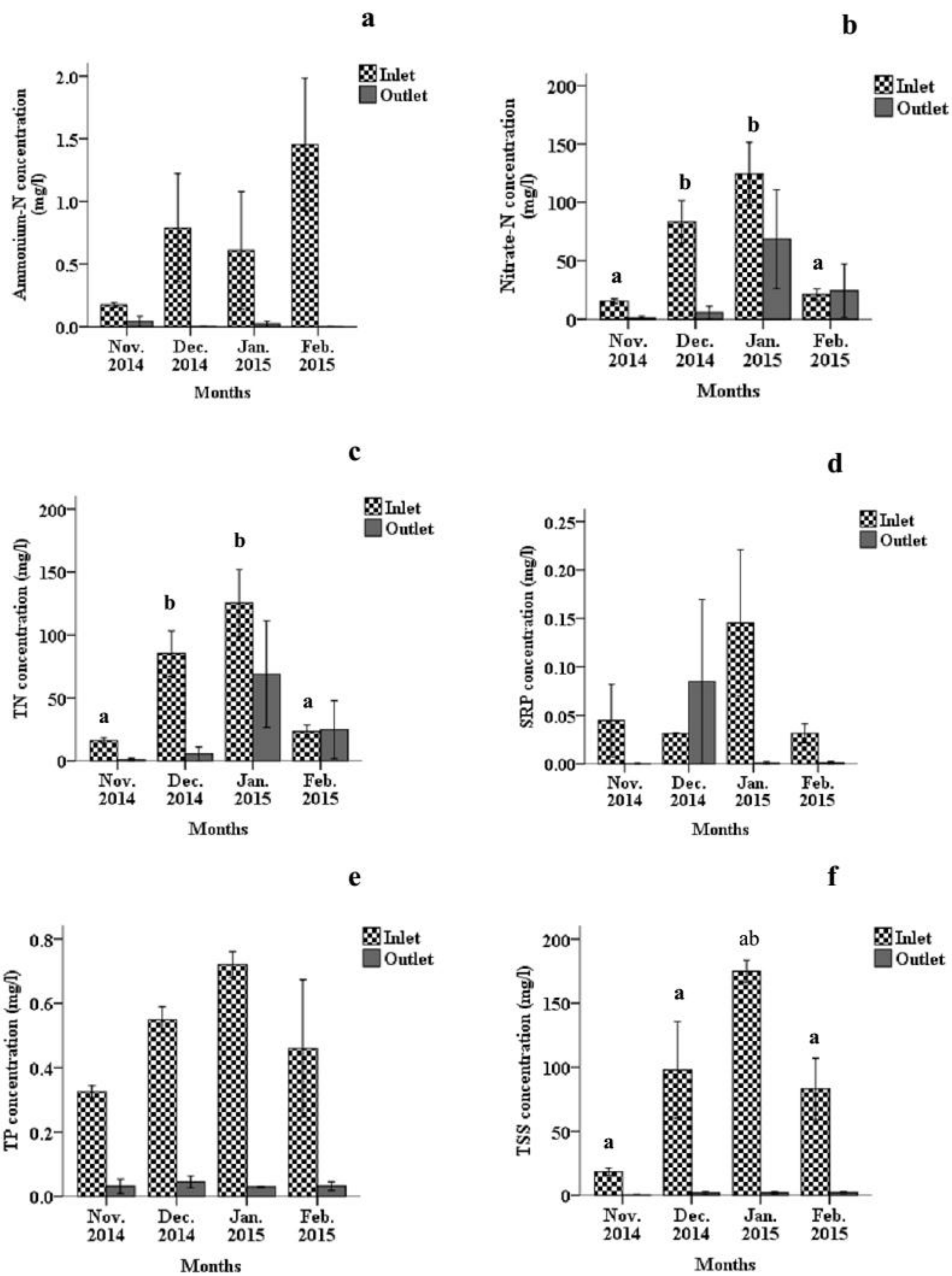

Figure 11: Temporal variation of nutrients concentration and TSS at S1 and S5 during study period (values presented as means ± SE, n = 9). Bars with the same letters are not significantly different (Tukey HSD *post hoc* test)

Temporal variations in mean BOD_5 and COD over time (temporal) during the study period are presented in Figure 12 (a-b). Variation of the BOD_5 with time at the inlet was insignificant (ANOVA, F = 1.233, d.f = 8, p=0.390, Figure 12a) during the study period. The mean values at the inlet ranged between 4.85 - 5.64 mg/l. The outlet mean BOD_5 also did not show any significant difference among the sampling months (ANOVA, F = 1.040, d.f = 8, P=0.451) with concentration ranging from 0.03 - 2.92 mg/l.

The Chemical Oxygen Demand concentration at the inlet and outlet of the constructed wetland did not vary significantly over the study period (ANOVA, F = 0.139, d.f = 8, p=0.933; F = 0.512, d.f = 8, p=0.692, Figure 12b) respectively. The inlet mean COD values were higher over the study period ranging between 135.33 - 490.33 mg/l with compared to values recorded at the outlet ranging between 25.33 - 214.96 mg/l.

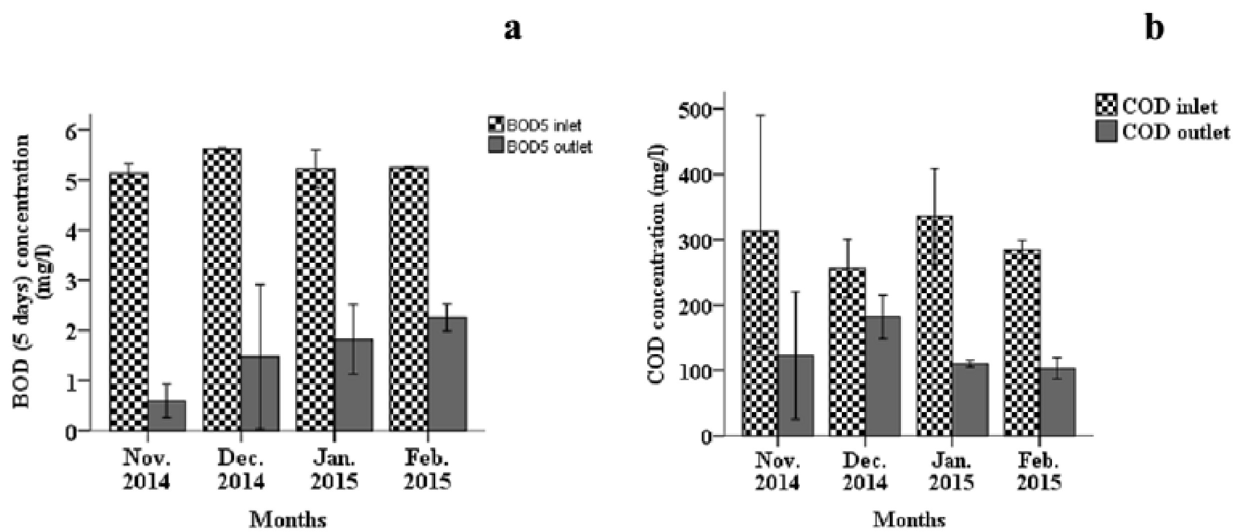

Figure 12: Temporal variation of BOD and COD at inlet and outlet of Finlay FWS CW during study period (values presented as mean ± SE, n = 9)

4.5 Finlays free water surface constructed wetland pollutants removal efficiency

4.5.1 Influent and effluent water quality

The mean influent and effluent concentration and the removal efficiencies of selected water quality parameters are presented in Table 6. The pollutants concentration of the incoming and outgoing wastewater at Finlays flower CW showed variation along the treatment pathway for all physico-chemical variables except SRP. Variation over the study period (temporal) was also noted for TSS, NO_3 and TN at the inlet with no change at the outlet over the study period. The SRP and TP concentrations at both inlet and outlet of the Finlays FWS CW were generally low among the sampling sessions and sometimes below detectable levels for soluble reactive phosphate. Pollutants removal efficiencies by Finlays FWS CW ranged between 57.2% to 98.1%. The CW revealed good performance in removing TSS (98.1%), NH_4-N (98%), TP (93.6%), NO_3-N (88.6%), TN (88.6%) and SRP (61.6%) However, the system efficiency in removing COD (57%) and BOD (69.6%) was low compared to other physico-chemical variables with the highest performance achieved for the NH_4-N and TSS.

Table 6: Pollutant removal efficiency at Finlays free water surface CW during the study period (Data presented as mean ± SE)

Parameters (mg l^{-1})	**n**	**CW inlet**	**CW 0utlet**	**Removal (%)**	***Kenyan standards (mg l^{-1})**
NH_4-N	57	0.94 ± 0.23	0.02 ± 0.01	98	100
NO_3-N	57	53.19 ± 12.28	6.09 ± 2.30	88.6	10
TN	57	54.79 ± 12.22	6.27 ± 2.37	88.6	20
SRP	57	0.06 ± 0.02	0.02 ± 0.01	61.6	15
TP	57	0.52 ± 0.07	0.03 ± 0.01	93.6	30
TSS	57	103.10 ± 24.56	2.01 ± 0.50	98.1	30
BOD_5	18	5.30 ± 0.09	1.62 ± 0.36	69.5	30
COD	18	295 ± 34.60	126 ± 20.76**	57.2	50

*Kenyan standard for effluent discharge into the environment extracted from NEMA (water quality) Regulations 2006 and ** with values beyond the NEMA standard

CHAPTER FIVE

DISCUSSION

5.1 Characteristics of the flower farm wastewater at Finlays constructed wetland

The Finlays flower farm FWS CW was observed with high efficiency in WW purification by significantly reducing nutrients, organic load and TSS at effluents. At the inlet of CW, hydrologic and physico-chemical characteristics of the WW was analyzed and presented in Table 3. The unique characteristics of the inlet WW observed were variability of the flow rate, nutrients and TSS concentration within a day and over time among the sampling sessions.

5.1.1 Hydrologic characteristics and influence on pollutants removal efficiency

Optimal hydraulic loading rate (HLR) and hydraulic retention time (HRT) are important to achieve good WW treatment efficiency in constructed wetlands. Past studies have revealed that pollutants removal efficiencies decreased significantly with increased loading rate and decreased retention time (Ansola *et al.*, 2003; Chung *et al.*, 2008; Trang *et al.*, 2010). Increased HLR, allows WW to pass quickly through the system reducing time available for removal processes to be efficient. This study showed that the removal performance of the Finlays FWS CW varied along the treatment pathway (spatial) due to variation of HLR and HRT among different purification cells. The mean retention time and loading rate over the study period was 14 days and 0.23 m/day respectively with high removal efficiencies in NH_4- N 98%, NO_3-N 88.6%, TN 88.6%, SRP 61.6%, TP 93.6%, BOD 69.5%, COD 57.2% and TSS 98.1%. The varied loading rate and retention time among the last two purification cells contributed the improved removal efficiency of the pollutants. The mean values of the HLR and HRT reported over the study period and the removal efficiencies are within the range reported in previous studies of the same system. The study conducted by Kotti *et al.* (2010) on the effects of operational and design parameters on treatment efficiency of the similar system in Greece confirmed 14-days HRT as adequate for acceptable removal of organic matter, nitrogen and phosphorus at high temperatures. He reported the removal efficiency at 14 days HRT for BOD (88.4%), COD (79.1%), TN (73.9%), SRP (73.7%), NH_4-N (65.4%) and TP (59.8%). The present study results revealed low performance in removal of BOD and COD compared to other studies regardless of the longer hydraulic retention time. This is in contrast to studies reporting higher removal of

COD at higher HRT. Ghosh and Gopal (2010) reported maximum removal of pollutants at HRT of 4 days, while Akratos and Tsihrintzis (2007) reported that HRT value greater than 8 days was needed to remove more than 90% of organic matter. Generally, Bojcevska *et al.* (2007) concluded that a constructed wetland typically requires a low hydraulic loading rate (HLR) and a long HRT to achieve efficient removal of pollutants.

The WW flow rate at the Finlays FWS CW showed a marked daily variation accounting for the variations over time with daily range of 3.1 l/min to 11.7 l/min at the inlet and 2.29 l/min - 10.64 l/min at the outlet of constructed wetland. During the study period water loss was not accounted for variation of effluent flow rate but probably the existing variability was influenced by water loss through evapotransipiration and seepage. This is confirmed by longer HRT at the third cell compared to the second purification regardless of close volume size indicating percolation of wastewater to the soil. The study done by (Kyambadde *et al.*, 2005) reported water losses at the extent of 19 mmday^{-1} to 25 mmday^{-1} for the constructed wetland unit planted with *Microbotryum violaceum* and *Cyperus papyrus* respectively. According to Lim *et al.* (2001) water loss from the wetland affects flow rate and alter effluent concentration levels and hence affecting treatment performance. However, a study conducted by He *et al.* (2012) also reported effluent concentration increase during warm season due to loss of water through evapo-transipiration and low flow at the effluent. Gerke *et al.* (2001) also concluded effluent nitrate levels of WWT plant increases when the flow rate is low. It is most likely that temporal variation of nutrients concentration observed in January 2015 was attributed by high water loss from the system and low precipitation reported in the month of January (1.5 mm) compared to other months over the study period.

As per engineer's specifications, the wetland was designed to receive approximately 30 m^3 per day but in high peak of flower production the wetland receives almost 52 m^3 per day. Variation in wastewater regime over time brings about temporal variation in operational parameters (HLR and HRT) and subsequently affecting treatment efficiency of the particular wetland. The Finlays constructed wetland over the study period had a mean inflow of 37.91 ± 9.96 m^3/day which exceeded the design capacity by 26.4%. Thus, the wetland is expected to be overloaded during wet season due to external water input which subsequently affects the operational parameters and treatment efficiency. The James Finlays flower farm management need to expand the size of the wetland to meet treatment efficiency of the currently wastewater generated from flower farm and provide extra capacity for hydrologic variability to protect the recipient aquatic environment from water pollution.

5.1.2 Physico-chemical variables and influences on pollutants removal efficiency

Monitoring of wastewater during the day showed marked variations of physico-chemical variables associated with different activities at different times of the day within the flower farm. The characteristics in relation to the on-going activities during the day includes post-harvest, fertigation, spraying, propagation and cleaning of the houses and containers used in fertilizer and other chemicals preparations. Monitoring of WW in the morning at 0800 hours revealed that the system was loaded with NH_4-N concentration which associated with post-harvest and fertigation activities. The high level of NH_4-N is attributed to the use of UREA fertilizer which is highly soluble and readily converted to NH_4^+ solution when in contact with water. This was also concluded by Bremner (1996) that UREA is quickly hydrolyzed to NH_4^+ solution when it comes in contact with water. Despite of the high level of NH_4-N at the inlet the wetland had low level at the effluent of about 0.02 mg/l. This could be attributed to oxygen availability along the treatment pathway ranging between 4.64 - 5.85 mg/l resulting to conversion of NH_4-N to NO_3 through nitrification. Indeed, the low oxygen reported at S2 ranging between 0.1 - 1.92 mg/l over the study period which could be attributed to microbial and chemical oxygen consumption during the nitrification process. Further, the physical parameters ranges observed along the treatment pathway during the study period including temperature (15.53 - 26.53 ^oC) and pH (4.64 - 8.59) are within range which supports nitrification process (Vymazal, 2007).

Influent wastewater monitoring around 1400 hrs revealed a peak concentration of NO_3-N, TN, TP and TSS associated partly with spraying but mainly propagation activities. Total nitrogen and nitrate concentration is respectively mainly attributed to the use of UREA fertilizer and the high dissolved oxygen at the inlet which supports the nitrification process. High concentration of TP at the inlet of CW is due to high concentration of largely inorganic compounds loading the system during the day. The soil used during propagation is partly released through the system during propagation unit cleaning and increase total suspended solids concentration in the system as observed ranging between 22.83 mg/l during fertigation activity to 306.91mg /l between around 1400 hrs associated with propagation activity.

Flower farm compartments cleaning at the end of the day was correlated with increase in phosphate (PO_4^-) concentration within wastewater. According to Kadlec (2005), phosphorus is removed from water through formation and accretion of new sediments and soils. The Finlays CW is about ten year old and has accumulated a large amount of sediments over time due to filtration and settling of the suspended solids. The accumulated solids and organic contents will slowly decay but need to be removed to avoid nutrient release back to the system. The continuous input of the sediments and the effects of phosphate release through cleaning of the compartments will provide more area for phosphorus binding. Generally, sediments accumulation over time will also affect design parameters including water depth, HRT, HLR and subsequently the removal efficiency.

5.2 Macrophytes characteristics at Finlays constructed wetland

Free water surface constructed wetlands performance depends on the availability and suitability of the existing vegetation, i.e. regulation of water flow, pollutants removal, biochemical transformations and stimulation of microbial activity (García-Lledó *et al.*, 2011). In the past studies, plant specific ability to maximize treatment efficiencies have been researched and documented. Macrophytes performance is normally influenced by the amount of standing biomass, plant litter or the oxygen transferred to the sediment through rhizosphere (Bachand and Horne, 2000). Vegetation contributes to nutrient uptake, filtration of pollutants and provides oxygen transfer mechanisms through roots and stimulates microbial activities (Maltais-Landry *et al.*, 2007). Additionally, vegetation provides habitats for aquatic wildlife and makes the system aesthetically pleasing. However, macrophytes species differ in nutrients accumulation governed by growth rate and extent of biomass development.

During the study period, Finlays FWS CW macrophytes above ground biomass and nutrients accumulation per unit area of the existing macrophytes were assessed. The study revealed *Cyperus alternifolius* having high biomass accumulation and generally the best performing in nutrients accumulation (Biomass = 8896 ± 195.61 gm^{-2}, N=49.82 gm^{-2} and P= 7.29 gm^{-2}). The average nitrogen accumulation in macrophytes above ground biomass was higher 8 times than phosphorus ranged between 3.73 - 57.7 g N m^{-2}. The observed range for N-accumulation conquers with reported nitrogen standing stock value of 2 - 88 g N m^{-2} (Vymazal, 1995; Vymazal *et al.*, 1999). However, concentration of phosphorus in the above ground biomass varied among species ranged between 0.58 - 7.29 g P m^{-2}. The observed value of P-accumulation is within the reported range of 0.01 - 19 g P m^{-2} (Vymazal, 1995; Vymazal *et al.*, 1999). Generally, high variability was observed among the species depending on individual plant capacity in building biomass and response to nutrients accumulation per unit area.

Several studies have reported the efficiency of macrophytes in nutrients removal, carbon source for denitrification process and providing habitat for microbial attachment (Stottmeister *et al.*, 2003; Zhang *et al.*, 2010; Zhang *et al.*, 2012). This study observed higher accumulation of nutrients per unit area for the emergent macrophytes compared to floating ones due to high standing biomass. Over the study period, macrophytes consistently accumulated more nitrogen (8 times) than phosphorus as observed in other studies. Several studies have documented higher N removal rates in wetlands containing macrophytes than in unplanted beds (Lin *et al.*, 2002; Ibekwe *et al.*, 2007). Kadlec (1993) and Toet (2003) have reported that removal of phosphorus through biomass harvesting has been found inefficient, with removal of less than 10% of the inflow concentration even in low loaded treatment systems. According to the study conducted by He *et al.* (2012) plants nitrogen accumulation contributes between 2 - 45 % of inorganic nitrogen removal from the system.

In addition, vegetation management is crucial for the sustainability of CW. Generally, results indicated *Cyperus alternifolius* performed better in terms of biomass accumulation and removal of both nitrogen and phosphorus while *Pistia stratiotes* was observed to have poor performance in accumulating both nutrients and low accumulation of biomass despite of its potential in total suspended solids removal due to roots structure through sediments trapping and filtration processes. Routine harvesting of the vegetation maintain the ratio of open water to ensure more aeration and removal of accumulated nutrients in biomass from the system (EPA, 1999).

Selected structural characteristics of *Pistia stratiotes* were assessed along the treatment pathway in three different purification cells (Cell 1 - Cell 3). Fresh weights, leaves and roots length were assessed along the purification trends and leaves showed no significant variation in length while fresh weight and roots lengths indicated significant difference among the cells. Fresh weight was high for *Pistia stratiotes* from surface cell 2 compared to others indicating better growth and biomass accumulation. This was attributed by nutrients availability (NO_3-N) at surface cell 2 which was assimilated by the macrophytes to build up more biomass. *Pistia stratiotes* roots length increased from surface cell 1 to cell 3. This is attributed to plant response to decreased nutrients availability in water column occasioned by wetland's efficiency in removing nutrients. Increased root length increases surface area available for uptake. The roots were observed to be thinner and longer towards the outlet of the wetland. The study conducted by Xie *et al.* (2005) on response of root morphology to water column nutrients availability revealed similar morphology indicating roots efficiency in nutrients acquisition. Rosolem *et al.* (1999) Xie and Yu (2003) also reported similar roots morphology as an adaptation to low nutrients environment. Indeed, the *Pistia stratiotes* roots response to nutrient concentration observed in this study is consistent with other similar previous studies. The roots of free floating macrophytes (water hyacinth) were thinner and longer when planted in low phosphorus concentration in aquatic environment (Xie and Yu, 2003).

5.3 Constructed wetland Treatment efficiency at Finlays flower farm

5.3.1 Spatial and temporal variation of physico-chemical variables and influence on treatment efficiency

The high temperature trends observed over the study period along the treatment pathway (S3 - S5) which are open surface cells could be attributed to the direct sunlight penetrating the surface water and the shallow depth, providing optimum heating of the water. The high temperature among the purification cells is important for purification process. Many past studies have revealed better wetlands performance with temperature above 15^{o}C as this allows bacteria responsible for nitrogen conversion to function properly and also fosters vegetation growth (Akratos and Tsihrintzis, 2007; Kadlec and Wallace, 2009; Kotti *et al.*, 2010). Stefanakis and Tsihrintzis (2012) have shown similar result concluding that at higher temperature above 15^{o}C, BOD and COD removal from CW is maximized. They also revealed a positive relation between nitrogen and phosphorus removal with increase in temperature. Phosphorus removal through sorption process is a temperature dependent reaction (Jin *et al.*, 2005) which increases when it is low. Vegetation grows vigorously at warm temperature optimizing nutrients uptake and enhancing their removal from CW system. According to Vymazal (2007) the response of the treatment systems to temperature variation has to do with microbial transformation such as organic matter breakdown, nitrification and denitrification. All these processes are favoured at high temperature resulting to high treatment efficiency. This significant variation of the water temperature could also be explained by increased insolation over the study (dry season) observed with less cloud cover and more warming to the system.

The observed high level of dissolved oxygen could be attributed to open water among purification cells which allows atmospheric gaseous exchange as well as CW design structures at inflow and outflow which provides more aeration to the flowing wastewater along the treatment pathway. According to Nivala *et al.* (2013), oxygen availability for treatment process can either be transferred through atmospheric diffusion or from within water column by phytoplankton. Additionally, the existing emergent and floating macrophytes release oxygen through their roots into rhizosphere and enhance aerobic decomposition and growth of nitrifying bacteria (Brix, 1994). However, open water allows light penetration which favour phytoplankton growth and ensure more oxygen release. Oxygen availability is a key driver for nitrification and organic biodegradation (Saeed and Sun, 2012). This phenomenon is verified in this study by the reduction of NH_4-N concentration from the inlet to the outlet by 98% during study period.

In this study, significant reduction of the electrical conductivity observed from the inlet to the outlet respectively ranging between 220.86 ± 12.38 to 97.25 ± 13.75 μScm^{-1}. This was attributed to wetlands efficiency in reduction of nutrients along the treatment pathway indicating a reducing accumulation of ions and suspended solids at Finlays FWS CW. The pH along the treatment pathway ranged between 4.64 - 8.59 at the inlet but stabilized at the outlet tending to neutral conditions (6.13 -6.88) and thus, indicating less organic decomposition activities and efficient capacity of the wetland in pH buffering. According to Vymazal (2007), pH below 6.0 affects nitrogen removal processes through denitrification and ultimately wetland performance. Generally, pH acts as a driver to anaerobic transformation process as within a range of 6.5 to 7.5

(similar range) provides suitable conditions for the methane forming bacteria which play a major role in organic matter removal process. The increase or decrease from the stated range above negatively affects bacterial activities which also reduces pollutants removal mechanism from the system (Vymazal, 1999).

The BOD_5 concentration compared to COD did not vary much at the inlet of the Finlays CW. High organic matter within WW contribute to BOD and COD while inorganic is mainly sulphate, chlorides and heavy metals (Lee and Nikraz, 2014). Both BOD_5 and COD are commonly used to measure organic matter content in wastewater. The ratio between the two parameters (BOD: COD ratio) is an indicator of both biological and chemical decomposition taking place during wetlands treatment process. Chemical Oxygen Demand results are typically higher than BOD_5 values, and the ratio between them always vary depending on the uniqueness of the WW. This ratio has been commonly used as an indicator for biodegradation capacity (Metcalf and Eddy, 2003). Generally, the BOD:COD ratio varies for different types of wastewater (Apadopoulous *et al.*, 2001). The Finlays flower farm WW was observed to have very low biodegradability index (B.I) indicating it is not an easily biodegradable waste. Table 7 shows the comparison of BOD_5, COD and BOD_5 to COD ratios of few selected wastewaters from other studies including recent study at Finlays flower farm WW. The Finlays flower farm wastewater was observed with inlet (raw) BOD_5 / COD ratio of 0.02 and outlet (after biological treatment) ratio of 0.01 which are very low values compared to other studies. Such low ratios were observed in studies done on treatment of pesticides wastewater (Barbusiński and Filipek, 2001; Chen *et al.*, 2007). For such low value of B.I < 0.3 obtained for WW at Finlays (B.I $=$ 0.02) indicates biodegradation will not proceed, because the WW generated inhibit bacterial metabolic activities either due to toxicity level or refractory properties (Abdallah and Hammam, 2014). These conditions affect acclimatization of microorganisms and require pre-treatment before biological treatment. According to Samudro and Mangkoedihardjo (2010) the BOD / COD ratio less than 0.10 (similar to Finlays WW) indicates the existence of large portions of hard biodegradable COD subsequently affecting treatment performance. The study conducted by Chen *et al.* (2007) on treatment of pesticides wastewater with low BOD ratio of 0.3 after pre-treatment revealed improved COD removal efficiency between 39.37% to more than 85% .

Table 7 Comparison of BOD_5, COD and BOD_5/COD ratios of selected wastewaters

Type of wastewater	**COD (mgl^{-1})**	**BOD (mgl^{-1})**	**BOD/COD**	**Reference**
Domestic sewage				(Kruis, 2014)
Raw	500	300	0.60	
After biological treatment	50	10	0.20	
Draft mill effluent				(Kruis, 2014)
Raw	620	225	0.36	
After biological treatment	250	30	0.12	
Pesticide industry effluent				
Raw	233.8	41.2	0.19	(Barbusiński and Filipek, 2001)
Finlays flower farm WW				
Raw	296	5	0.02	This study
After biological treatment	127	2	0.01	

5.3.2 Influent and effluent concentrations and pollutants removal efficiency

Constructed wetlands constitutes complex ecosystems, biological and physical components which interacts and in the process removing pollutants (Maine *et al.*, 2007). The Finlays free water surface constructed wetland showed high efficiencies in treating wastewater from flower farm by significantly reducing TSS, nutrients and organic load (BOD_5 and COD). However, many CW studies focusing on different wastewater characteristics have been reported in Kenya with significant reduction of pollutants (Nzengy'a and Wishitemi, 2001; Bojcevska *et al.*, 2007; Kimani *et al.*, 2012). The Finlays Chemirei CW was most efficient in TSS (98.1%), NH_4-N (98%), TP (93.6%), NO_3-N (88.6), TN (88.6), BOD_5 (69.5), SRP (61.6), and COD (57.2%). During study period, total suspended solids decreased significantly from the inlet to the outlet. Despite the influent TSS concentration variability during the study period the wetland generally maintained low concentration of TSS at the outlet. Total suspended solids in FWS CW are mainly removed through sedimentation, filtration, aggregation and surface adhesion (Vymazal, 2014). The removal efficiency of TSS (98.1%) over the study period was attributed to sedimentation rate, where sedimentation chambers enhances sediment settling and the *Pistia stratiotes* roots were observed to have high trapped suspended solids during the study period.

Hydraulic loading rate and hydraulic retention time also affect TSS removal efficiency during this study between S1 and S2. Despite of the significant variation between the two sampling points over the study period, the mean concentration for TSS remained high at S2 (28.5 mg/l) due to high HLR (0.75 m/day) and low HRT (2 days) between the two sampling sites compared to other sites. Kadlec and Wallace (2009) reported that at high HLR and low HRT, the treatment system does not provides sufficient time for filtration, trapping and settling of the suspended solids. However, the result reported is within the range of TSS removal efficiency reported by Kimani *et al.* (2012) on similar study at the Homegrown Ltd flower farm at Naivasha Kenya. The suspended solids removal was efficient over the study period and produced final average effluent concentration of 2.01 ± 0.50 mg/l which is far below Kenyan effluent standard of 30 mg/l.

Ammonium -nitrogen, NO_3-N and TN concentration were significantly reduced by 98%, 88.6% and 88.6% respectively over the study period. Generally, high concentration values were observed at the inlet during study period. This was attributed to the application of nitrogenous fertilizer during flower farming and also during of the fertigation compartments. The leading nitrogen removal from the system is through bacterial transformation. Nitrifying bacteria transform NH_4-N under aerobic condition into NO_3-N which is further transformed under limited oxygen through denitrification to free atmospheric nitrogen (Verhoeven and Meuleman, 1999). The reduction of NH_4-N from S1-S5 can be explained by high oxygen levels from S1, S3 - S5 and partly being released from rhizosphere which contribute to conversion of NH_4-N to NO_3-N. Nitrate-N concentration partly is assimilated by the existing macrophytes and remaining removed through denitrification process. Nitrogen removal through plant accumulation in biomass was estimated for the twelve existing species of macrophytes at Finlays CW. The highest nitrogen accumulation was observed in *Fimbristylis complanata* (57.70 g m^{-2}) and the lowest in *Pistia stratiotes* (3.73 g m^{-2}). The macrophytes function as a temporary nutrients storage, therefore regular harvest removes the nutrient from the system.

Soluble reactive phosphate and TP concentration at Finlays CW were generally low over the study period. Despite the low concentration, significant reduction of the nutrient was observed for TP (93.6%) and SRP (61.6%). The low concentration was attributed to phosphate free flower farming practices and also the use of phosphorus free detergent at Finlays flower farm (Personal communication with Merry Opisa at Finlays Farm). Free water surface provides continuously removal of phosphorus but at relatively slow rate through adsorption, absorption, complexion and precipitation (Vymazal, 2014). Phosphorus removal through biomass accumulation is not effective as observed from the existing twelve species of macrophytes which had low accumulation values compared to those of nitrogen. However, the highest phosphorus accumulation was observed in *Cyperus alternifolius* (7.29 g m^{-2}) and the lowest recorded at *Cyperus rotundus* (3.73 g m^{-2}). The long term phosphorus removal by FWS CW is known to occur through sedimentation and substrate fixation (Healy and O'Flynn, 2011). Over the long period of time phosphorus is released back to water upon phosphorus substrate saturation. The Finlays CW is about ten years old now with sediment accumulation reducing water depth and volume which need to be removed to avoid phosphorus release back to water.

The BOD_5 and COD concentration removal over the study period were 69.6% and 57.2% respectively. In wetlands treatment systems, BOD is mainly removed by microbial activities with plants and litter providing surface area for biofilm growth. Plants provides suitable conditions for settling of suspended solids and particulate BOD for further degradation through aerobic or anaerobic process depending on oxygen availability (McCourt and Woolley, 1997). Past studies also revealed that COD removal within wetlands systems depends on macrophytes types and water level within the system enhanced by oxygen availability at root zone and carbon release (Stottmeister *et al.*, 2003; Sun *et al.*, 2009). The unexpected low removal efficiencies for the BOD and COD over the study period may not have been influenced by physical chemical variables which have been documented to affect microbial activities (Spieles and Mitsch, 1999; Feng *et al.*, 2008). During the study period the temperature ranged between 15.53 - 26.53^{o}C which is within the optimum temperature range for microbial activities (Akratos and Tsihrintzis, 2007; Kotti *et al.*, 2010). Therefore the low BOD and COD removal performance might be attributed to existence of non-biodegradable compounds which need more hydraulic retention to be degraded.

During the study period observations were conducted of the river water quality upstream and downstream of the discharge point (outlet of the wetland). The results indicated no impact of the effluent from the wetland on the river water quality. There is no significant variation of the upstream and downstream water quality during study period. An unexpected observation was the high concentration of nitrogen in both upstream and downstream of the river indicating upstream water pollution source. The range recorded was 27.35 ± 1.50 and 26.18 ± 1.96 mg/l of TN in upstream and downstream respectively. Generally, the wetland was efficient in removal of all pollutants by discharging concentrations below the requirements of Kenya regulatory standard except for Chemical Oxygen Demand which was above the requirement.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

- The Finlays free water surface CW treatment system played significant role in Pollutant retention hence maintaining low concentration of the effluent regardless of daily variability in hydrologic and physico-chemical characteristics
- The different macrophyte species in the wetland revealed varying capacity of nutrients accumulation hence influencing treatment efficiency. Plants also contributed to TSS removal through filtration and surface area provision for biofilm growth enhancing BOD and COD removal.
- The Finlays free water surface constructed wetland showed spatial and temporal variation of the pollutants concentration but maintained low concentration of the effluent indicating its efficiency in pollutants removal

6.2 Recommendations

- Wastewater storage capacity and constantly inflows should be maintained to avoid variability which can affect treatment efficiency and operational parameters
- Macrophytes species should be selected based on the current findings in nutrient accumulation to maintain high level of pollutants removal
- Studies on microbial population dynamics and water balance of the flower farm constructed wetland should be undertaken to confirm the influence of the low BOD to COD ratio in the system and hydrological aspect
- Periodic removal of sludge to maintain the design capacity of Finlays constructed wetland should be done to maintain removal efficiency

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APPENDICIES

Appendix I: Plant analysis sheet from Kenya Agricultural Research Institute

PLANT TEST REPORT

KENYA AGRICULTURAL AND LIVESTOCK RESEARCH ORGANIZATION KALRO NJORO
P.O BOX PRIVATE BAG NJORO
TEL: 020351865
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ANALYTICAL RESULTS

SAMPLE NAME	LAB NO	*N* (%)	*P* (mg/Kg)
Cyperus rotundus	02-14/4562	1.31	1160
Cyperus compactus	02-14/4563	1.31	1194
Fimbristylis complanata	02-14/4564	1.87	1160
Sphaeranthus suaveolens	02-14/4565	1.68	1433
Myriophyllum aquaticum	02-14/4566	1.87	1604
Cyperus haspan	02-14/4567	1.49	1911
Canna australia	02-14/4568	2.43	2900
Cyperus alternifolius	02-14/4569	0.56	819
Cyperus latifolius	02-14/4570	0.93	1740
Crassula aquatica	02-14/4571	2.24	1876
Zantedeschia aethiopica	02-14/4572	1.49	4913
Pistia stratiotes	02-14/4573	1.12	4333

Appendix II: Macrophytes pictures at Finlays free water surface constructed wetland

Cyperus rotundus

Cyperus compactus

Fimbristylis complanata

Sphaeranthus suaveolens

Myriophyllum aquaticum

Cyperus haspan

Canna australia

Cyperus alternifolius

Cyperus latifolius

Crassula aquatica

Zantedeschia aethiopica

Pistia stratiotes

Appendix III: Results of one way ANOVA for the nutrients, TSS and organic load

		Df	F	Sig.
NH4	Between Groups	3	7.788	0.000
	Within Groups	40		
	Total	43		
NO3	Between Groups	3	13.369	0.000
	Within Groups	40		
	Total	43		
TN	Between Groups	3	14.722	0.000
	Within Groups	40		
	Total	43		
SRP	Between Groups	3	1.970	0.134
	Within Groups	40		
	Total	43		
TP	Between Groups	3	20.125	0.000
	Within Groups	40		
	Total	43		
TSS	Between Groups	3	39.667	0.000
	Within Groups	40		
	Total	43		
BOD	Between Groups	3	18.185	0.000
	Within Groups	20		
	Total	23		
COD	Between Groups	3	9.111	0.000
	Within Groups	30		
	Total	33		