

Seasonal Variability of Water Quality and Nutrient Removal Efficiency of a Restored Wetland

**Kunan Brewer Vesselly ^{(1)*}, Alfonse Opio ⁽²⁾, Majaliwa Mwanjalolo ⁽³⁾,
Frank Kansiime ⁽⁴⁾**

⁽¹⁾South China Agricultural University

⁽²⁾Faculty of Science, Gulu University

⁽³⁾Department of Geo-Informatics and Climate Sciences, Makerere University

⁽⁴⁾Department of Environmental Management, Makerere University

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Abstract

Most studies of wetlands in Uganda use for water and wastewater treatment have focused on natural undisturbed pristine wetland and constructed wetlands. There exists a gap in literature surrounding treatment abilities of restored wetland or wetlands on a path to recovery. Water quality parameters were sampled covering wet and dry seasons in a restored wetland. Soil properties were also assessed and compared with a referenced natural site. The objectives of the study were to (i) determine the effects of wetland restoration on nutrient retention and release, (ii) analyze temporal dynamics of water quality parameters in the restored wetland, and (iii) describe soil properties in depths of the restored wetland in relation to a reference natural site. Values of pH, electrical conductivity (EC), temperature, total dissolved solids (TDS), TN and NO₃-N showed significant differences across seasons. The wetland demonstrated little water quality benefits but the overall nutrient removal efficiency when compared to literature values was found to be not impressive. Rates for P and N removal were between 3.5 - 19% and -10.8 – 32.4% respectively. These results could be attributed to flooding, low residence time of the water, small size of the wetland, low influent load, extra nutrient inputs from fertilizers and pollution sources as well as release from soil. We recommended that management activities like harvesting; redesigning the channels for water distribution throughout the system and removal of invasive plant species be carried out. This study will form a baseline in understanding the ecology of restored wetlands in Uganda.

Keywords: wetlands, Restoration, water quality, nitrogen, phosphorus

1. Introduction

Wetlands ecosystems are amongst the most important providing provisioning, regulating, supporting and cultural services globally (Millennium Ecosystem Assessment 2005; Mitsch and Gosselink 2015). Provisioning services include fisheries support and direct food production. Regulating

* Corresponding author: Kunan Brewer Vesselly
e-mail: kbvesselly@gmail.com

services include improving water quality, protecting coastlines from natural disasters promoting carbon sequestration, and protecting the habitat of rare and endangered species. Cultural services are involved with various activities linked to this specific landscape, i.e., ecology education, ecotourism, bird-watching, etc (Mitsch et al. 2015). Wetland degradation, linked to anthropogenic pressures and climate change is a major global problem. Despite concerted efforts to restore natural wetlands for human well-being, global change and intense anthropogenic pressure have destroyed more than half of global wetlands during the last century (Wang et al. 2012; Davidson 2014).

To regain services provided by wetlands, management agencies are increasingly turning to wetland restoration (Mitsch et al. 2001; Zedler 2003). Wetlands restoration is a systematic process (Kirk et al. 2004). Typically, wetlands restoration focuses on restoring three key components: hydrology, biology and soil of wetlands. Investigation of these components in restored ecosystems and how they change during ecosystem development is a necessary research area and has therefore received a great deal of research attention in recent years (Lu 2008; McCauley et al. 2013).

Wetland hydrology is often considered as the most critical component to wetland restoration success (Kusler and Kentula 1990). Water is an important component of wetland hydrology (Effendi 2016) and water quality is an indicator of water's suitability for maintaining various industrial applications and processes, as well as a potential factor in supporting biodiversity and ecosystem function (Khan et al. 2015; Duan et al. 2016). Water quality is generally expressed as the concentration of inorganic and organic materials in the water, and its degradation can seriously affect wetland ecosystems function (Duan et al. 2016; Jiang et al. 2015). Like hydrology, the restoration of wetland soil properties is another important factor in restoration, as soils are the physical foundation of wetland ecosystems (Stolt et al. 2000).

Wetlands in Uganda have come under considerable pressure and most of them are on the brink of total degradation due to the uneven nature of activities affecting them. Nowhere is this more evident than in the wetlands that surround the world's largest tropical lake, Lake Victoria, where a growing population and developing economy continue to put pressure on these vital ecosystems which are relied upon to attenuate industrial, urban and agricultural pollution and supply numerous services and resources (Kansiime et al. 2007). Uganda has an area of 241,550.7 square kilo kilometers (sq.km), of which 41,027.4 sq km are open water bodies and wetlands while 200,523.2 sq km is land (UBOS 2014).

In Uganda, the National Environment Management Authority (NEMA) and the Wetland Management Department of the Ministry of Water and Environment institute penalties that range from levying fines to ordering the restoration of wetlands that are degraded severely by encroachment. This was the case with an urban wetland, Nakyesanja, in Uganda's Wakiso district that was ordered restored by NEMA to be carried out by the encroacher – the Kawanda Secondary School. The School had encroached on the wetland to create playground for its students. The main goal of the restoration was to reverse the impacts of the disturbance by reinstating wetland hydrology and planting obligate and facultative wetland plants (Zedler 2003; Verhoeven et al. 2006); in this case the predominant plant was *Cyperus papyrus* L.

A review of literature found gaps in the ecology of restored wetland systems in Uganda as most studies focus on natural and constructed wetlands use for wastewater treatment. Our main objectives were to: (i) determine the effects of wetland restoration on nutrient retention and release, (ii) analyze temporal dynamics of water quality parameters in the restored wetland, and (iii) describe soil properties in depths of the restored wetland in relation to a reference natural site. On a larger scale, the results and restoration processes highlighted herein could be used to foster wetland conservation efforts in Uganda and beyond.

2. Materials and Methods

Study Areas

The studied wetland is located in Wakiso District adjacent the Kawanda Research Center along the Kampala-Gulu highway in Uganda (Fig. 1.). The restored wetland, Nakyesanja, lies directly opposite Kawanda Secondary School in Nabweru sub-County at the following coordinates 32°32' 3.066'' N; 0°24' 14.7132'' E. The estimated terrain elevation above sea level for Nakyesanja wetland is 1160 meters. The estimated size of this wetland is 0.4 hectares and was restored in 2009. Soil samples were also collected from a referenced natural wetland, Kiryagonja, located in Gombe sub-County. The referenced natural wetland was located at the following coordinates: 32°29' 33.126'' N; 0°30' 54.5184'' E with an estimated terrain elevation above sea level of 1150 meters.

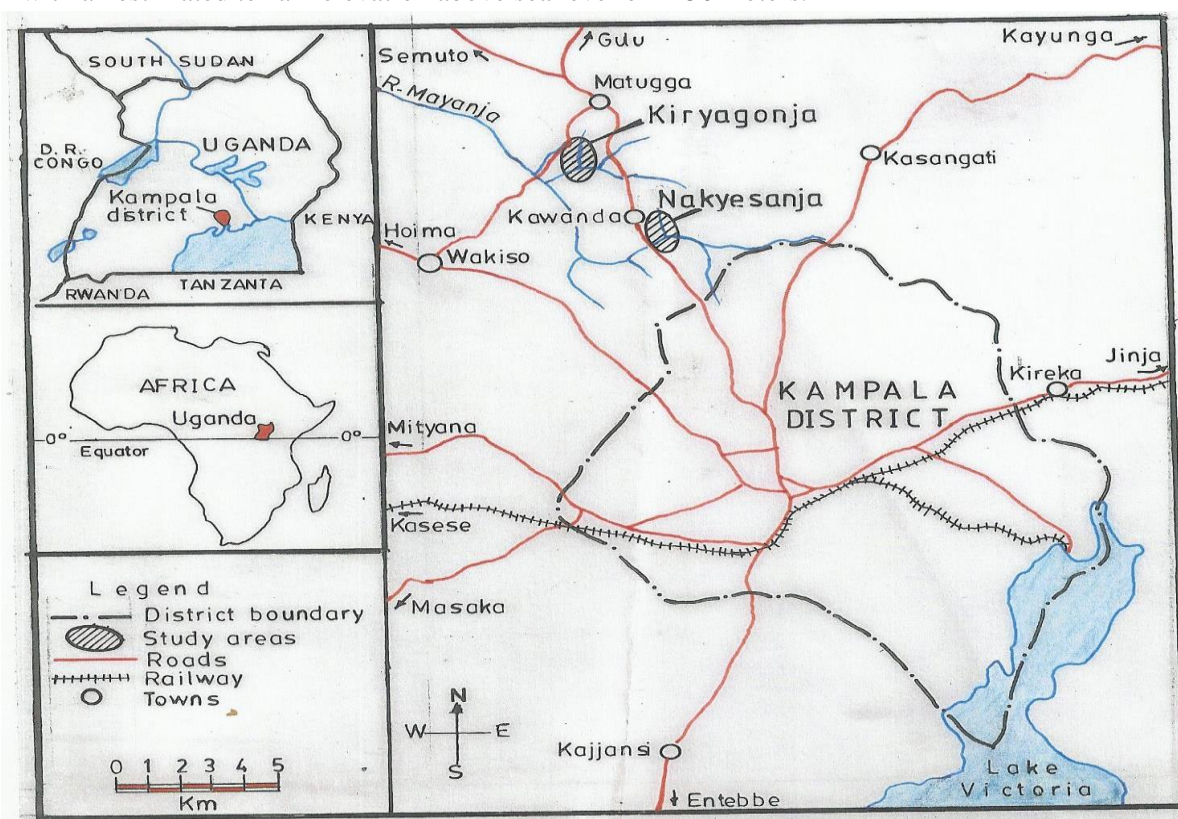


Fig. 1. Map of the Study Areas showing the location of Nakyesanja and Kiryagonja Wetlands.

Water Sampling Procedure and Chemical Analysis

Water samples were collected from two sites in the restored wetland only so as to establish whether the quality of water improved as the water flows through the wetland. Samples were taken at the inflow into the wetland and at the outflow from the wetland. Sampling was done covering wet and dry seasons. For the wet season, water sampling was done from the beginning of October to early December 2014, and data for the dry season was captured from Mid-December 2014 to late February 2015. Each sampling period covered 10 weeks x 2 sites x 2 seasons making a total of 40 samples. Samples were collected in a 500ml plastic bottle labeled with the date and site number. The sample bottles were placed in a cool box and transported to the laboratory for analysis. The flow rate was also determined *in situ* by using a 20 liter bucket and a stopwatch. The load of every nutrient was calculated at the inflow and outflow by multiplying the concentration by the flow rate. After which the efficiency

of nutrient removal was calculated using the formula: $(\text{Load Inflow} - \text{Load Outflow}) / \text{Load Inflow} * 100\%$. Net nutrient flux was simply computed as inputs minus exports of a given concentration per day.

The following parameters were measured *in situ*: pH, electrical conductivity, total dissolved solids (TDS), and temperature using a Hanna Waterproof meter HI 98129. The other parameters including total phosphorus (TP), total nitrogen (TN), ammonium-nitrogen ($\text{NH}_4\text{-N}$), nitrate-nitrogen ($\text{NO}_3\text{-N}$) and soluble reactive phosphorus (SRP) were analyzed in the laboratory according to American Public Health Association's (APHA) standard methods for the examination of water and wastewater (APHA 1998). Ammonium-nitrogen was determined by titration using Nessler's reagent. Nitrate was determined using Devarda's alloy method. Soluble reactive phosphorus was determined using the ascorbic acid method in a Phenolphthalein indicator solution. Total nitrogen and total phosphorus were determined using the Persulfate digestion method by adding persulfate solution and placing in an oven for one hour at a temperature of 105°C .

Soil Sampling

Soil samples were collected from the same depths in both restored and a referenced natural site using an auger. The depths collected were: 0 – 10 cm, 10 – 30 cm and 30 – 60 cm. Soil samples were taken once to understand the concentration of soil properties and their influence on water quality changes. Approximately one kilogram of sub-sample from each soil depth was taken and put into plastic bags, air-dried to constant weight at room temperature, crushed, homogenized, and passed through a 2mm sieve before laboratory analysis. Soil colour and texture were determined *in situ*. Soil colour was determined using Munsell Standard Color Charts (Munsell Color Chart, 1994). The textural classes of soil were named using FAO Guidelines for Soil Description (Jahn et al. 2006).

Laboratory analyses of soil properties

The following variables were analyzed in the Soil Science Laboratory at Makerere University: pH, conductivity, organic matter, calcium, nitrogen, available phosphorus and potassium. These parameters were analyzed using methods described by Okalebo et al. (2002). Calcium and Potassium in the soil were analyzed using the Flame photometer on an ammonium acetate extract. Phosphorus was determined using a spectrophotometer using Murphy Riley Molybdenum blue method at a wavelength of 880nm. Soil pH and electrical conductivity were measured in a soil-water solution at a ratio of 1:2.5 using pH and conductivity meters respectively; Total nitrogen (N) was determined calorimetrically following digestion; and Organic matter (OM) was determined using Black and Walkly oxidation method. Soil Organic carbon was determined as a percentage of organic matter by dividing organic matter by 1.72 (Landon 1991).

Statistical Analysis

To examine differences in water chemistry in seasons and between sites we used analysis of variance (ANOVA). In some instances data were log-transformed to meet assumptions of normality. All statistics were computed at a 95 percent confidence level ($p \leq 0.05$).

Soil results were interpreted using their associated ratings from Booker Tropical Soil Manual (Landon 1991) and Okalebo et al. (2002). The interpretations described variation by looking at the ranges of each soil property in the different depths of the restored and referenced natural wetlands.

3. Results

Temporal variation in water quality parameters

The results of this study reveal significant temporal variance of pH, Discharge, Electrical Conductivity (EC), Temperature and Total Dissolved Solids (TDS) (Tab. 1). All the water samples considered here were alkaline (pH values between 7.3 – 7.8). Results show that the pH value recorded in dry was higher than that of the wet season. EC recorded significant higher value in the wet season in comparison to the dry season. The value of temperature though significant higher in the dry season fell with the standards for effluent discharge in Uganda. Similarly, TDS value fell below standards for effluent discharge in Uganda (1200 mg/l) and was significantly higher in the wet season.

Tab. 1. Difference in Mean values \pm standard error of water quality parameters during the dry and wet season and their respective p values (n = 40).

Parameters	Dry Season	Wet Season	P-Value
pH	7.6 \pm 0.021	7.7 \pm 0.027	0.016
Discharge (l/s)	0.86 \pm 0.05	3.62 \pm 0.23	< 0.001
EC (μ S/cm)	246.1 \pm 4.8	309 \pm 4.4	< 0.001
Temperature ($^{\circ}$ C)	22.52 \pm 0.32	21.6 \pm 0.29	0.043
Total Dissolved Solids (mg /l)	122.9 \pm 2.39	154.4 \pm 2.23	< 0.001

Nutrient Removal Rates and Nutrient Flux Balance

The data assembled in this study show that nutrient removal rates varied over both seasons (Tab. 2). Particularly, during the dry season N removal rates ranged from 15.4% to 19% and from 0% to 9.5% in the wet season depending on types and inflow loading. Recorded P removal rates ranged from 26% to 32.4% in the dry season and -10.8% to 2.8% in the wet depending on different types and inflow loading.

Tab. 2. Nutrient removal rates of different seasons in the restored wetland.

Parameters	Season	Load Outlet (kg / day)	Removal Rate
N	Dry	2.97x10 ⁻⁴	15.4 - 19%
	Wet	1.57x10 ⁻³	0 – 9.5%%
P	Dry	7.7x10 ⁻⁴	26 – 32.4%
	Wet	3.29x10 ⁻³	-10.8 – 2.8%

The figures (Fig. 2A – 2E) display the net nutrient flux of TN, NH₄-N, NO₃-N, TP and SRP. In a case where inputs were greater than exports (positive value), the restored wetland was considered to be retaining the nutrients; but if the given inputs were less than the exports (negative value), it was considered release by the ecosystem. The restored wetland was predominantly a sink of TN in the dry season as the inputs was larger than the exports for most of the dry season. The wetland was not retentive of TN during the wet season as the wetland kept changing from a source to a sink but the overall release was more. It was a similar pattern observed for NH₄-N for both dry and wet seasons. Inputs were higher than exports for NO₃-N in the dry and the restored wetland release NO₃-N throughout the wet season. Even though the wetland fluctuated between being a source and sink for TP during the dry, the retention was relatively higher than the wet. Net fluxes for SRP were retained in the early and late dry season. Huge release of SRP was observed in the early wet season but there was an improvement as the season progressed.

Relationship between Temperature and Water Quality Parameters

Figure F displays the linear regression between temperature and $\text{NO}_3\text{-N}$ in the restored wetland. There was a strong and positive correlation ($R = 0.94$; $p < 0.05$) observed between temperature and $\text{NO}_3\text{-N}$. The relationships between temperature and other water quality nutrients were not significant.

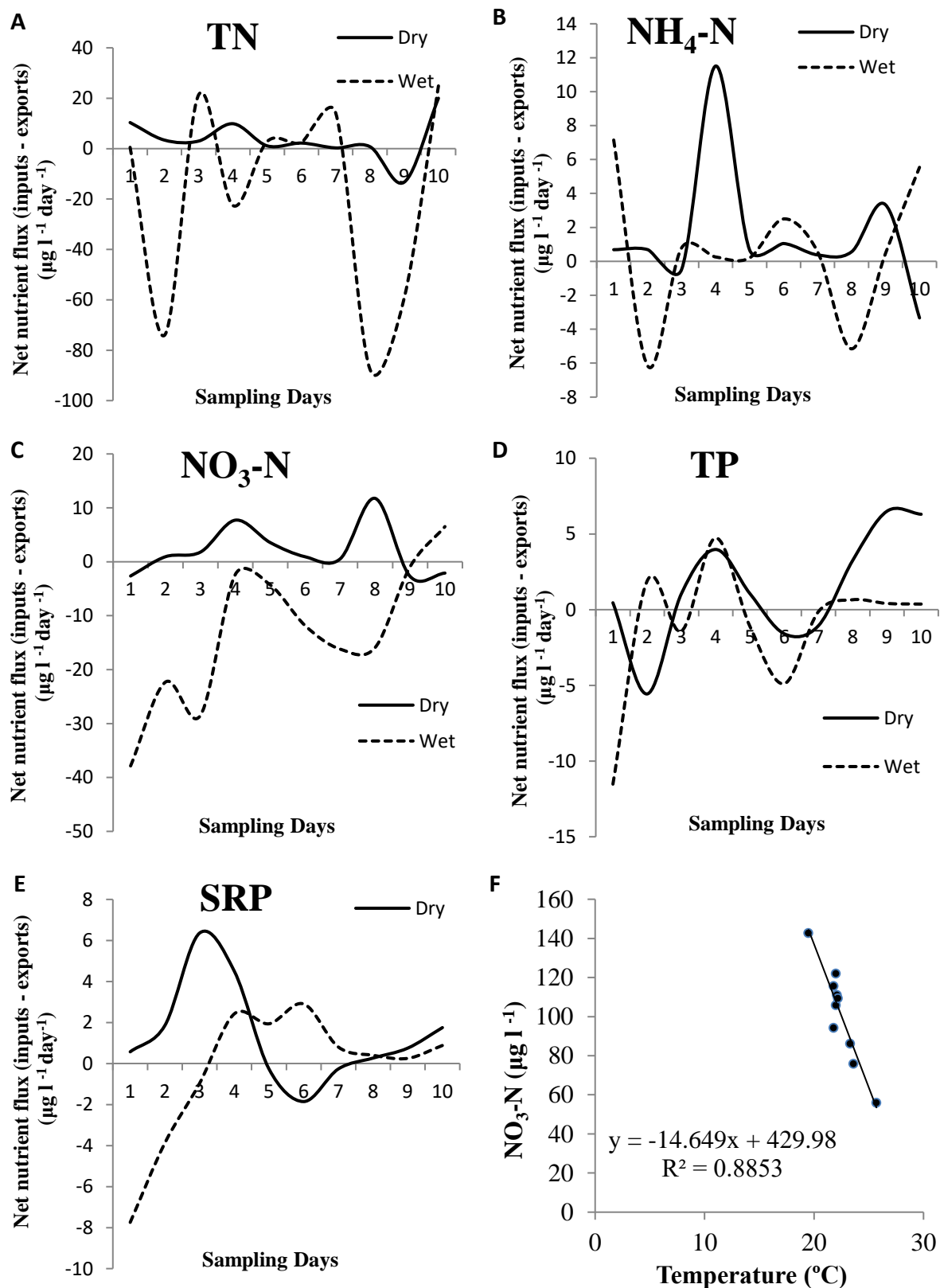


Fig. 2A – 2F. The net nutrient flux of TN, $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$, TP and SRP.

Tab. 3. Physico-Chemical properties of the restored wetland and a referenced natural wetland soils.

Wetland Types	Depth (cm)	Texture	Color	pH	EC (µ/s)	OM (%)	OC (%)	N (%)	P (ppm)	K (Cmols/Kg)	Ca (Cmols/Kg)
Restored	0-10	Silty Clay Loam	Reddish Brown	6.5	141	10.6	6.2	0.27	3.77	0.25	6.56
	10- 30	Silty Clay Loam	Reddish Black	6.3	44	2.47	1.4	0.28	3.94	0.3	6.53
	30 - 60	Sandy Clay	Dark Gray	6.1	56	2.46	1.4	0.24	3.46	0.41	6.01
Natural	0-10	Silty Clay Loam	Dark Gray	6.7	134	12.07	7	0.21	3.47	0.34	8.44
	10-30	Sandy Clay	Dark Gray	5.1	59	10.47	6.1	0.29	3.47	0.21	6.44
	30-60	Sandy Clay Loam	Gray	5.1	23	1.79	1	0.17	1.69	0.17	3.75

Tab. 4. Literature Values of N and P Removal Rates ($\text{g m}^{-2} \text{y}^{-1}$ and % of influx) for Restored and Constructed Wetlands.

Wetland	Wetland Size (ha)	N ($\text{g m}^{-2} \text{y}^{-1}$)	% influx	P ($\text{g m}^{-2} \text{y}^{-1}$)	% influx	Reference
Palustrine wetlands, WA, USA	1.5 - 2	ND	ND	0.4 - 3	7.5 - 82	Reinelt and Horner (1995)
Restored agricultural wetland, MD	1.3	-1.1 - 4.5	-8.4 - 38	-0.28 - 2.8	-11 - 59	Jordan et al. (2003)
Agricultural wetlands, OH, USA	1.2	39	40.2	6.2	56.2	Fink and Mitsch (2004)
Created river wetlands, OH, USA	1	58-66	30	5.2 - 5.6	50	Mitsch et al. (1998)
Constructed agricultural wetlands, Lake Bloomington, IL	0.4 - 0.16	14.2 - 23.2	23 - 44	0.06 - 0.1	40 - 79	Kovacic et al. (2006)
Constructed wetlands, Norway	0.35 - 0.09	50 - 285	3 - 15	26 - 71	21 - 41	Braskerud (2002)
Constructed wetland, Victoria Australia	0.04	23	11	2.8	17	Raisin et al. (1997)
Nakyesanja Wetland, Uganda	0.4	0.0045	3.5 - 19	0.0040	-10.8 - 32.4	This study

Soil properties in the restored and referenced natural wetlands

Physico-Chemical properties of the restored and a referenced natural wetland soils are presented in Table 3. The pH of the restored wetland was slightly alkaline and did not vary widely across the layers. In the natural wetland pH reduces drastically with depths (becoming acidic). Soil organic matter tended to decrease with depth in both wetlands. Though the natural wetland had relatively higher organic matter in the top layer than the restored wetland, OM fell within the same range. The top layer of the restored wetland had relatively higher concentration of Nitrogen (N) (0.27%) than the top layer of the natural wetland (0.21%). There was relatively higher concentration of Phosphorus (P) in the top and sub-surface layers of the restored wetland than the natural wetland. P was increasing with depth in the restored while it was constant in the first two layers in the natural wetland. There was an opposite trend observe for Potassium (K) in the wetlands. With a relatively higher concentration in the top layer of the natural wetland, K was decreasing with depth. K was increasing with depths in the restored wetland. There was relatively lesser concentration of Calcium (Ca) in the top layer of the restored wetland in comparison to the natural wetland.

4. Discussion

Temporal variability in water quality parameters

The pH is one of the most important indicators of water quality in aquatic ecosystems (Khan et al. 2013; Wang et al. 2017). All of the samples analyzed here fell within the recommended range of pH values, between pH 6.5 and pH 8.5 (World Health Organization 2001) as Uganda has aligned its water standards to international standards (UNBOS 2019). The water pH was higher than pH value (6.6 – 6.8) reported for constructed wetland planted with papyrus (Kyambadde et al. 2004) probably because of the presence of less humus and an increase in algae photosynthesis which led to the production of more hydroxyl. The shallow water depth, open canopy and the motionless water surface of the restored wetland acted to increase water temperatures in the warmer months. The high EC level in the rainy months could be associated with polluted runoffs from domestic and industrial sources especially from the Kampala Capital City Authority (KCCA) garbage collection point in Kawanda town. A similar result was also reported by Kansiime et al. (2007) in which they attributed increase in conductivity and attributed that to polluted runoff in their study of pristine and disturbed wetlands in Uganda. The higher TDS in the wet season may be attributed to high surface runoff, erosion, stormwater and urban runoff, the transport of decay plants and animals and bricks making. Another reason could be during the wet season the water was sharply more oxygenated and contain high ion concentration due to higher salinity water seepage (Cabezas et al. 2009).

Restoration Effects – Nitrogen Removal

The removal rates for $\text{NH}_4\text{-N}$ were low (9.5 – 19%) and this could because of the short residence time in the restored wetland and the small size of the wetland which made plant uptake to be negligible. This is in agreement with Moreno et al. (2007) who reported that larger wetlands removed more N than medium and small ones. The results of this study also suggest that nitrification could have been inhibited in the flooded slightly acidic soil. The removal rates for $\text{NH}_4\text{-N}$ were similar to those reported for constructed wetland pilot units in Kirinya wetland (Okurut 1999) which was < 20%. Ammonium-nitrogen struggle to be removed as temperature and pH were not within the range that could support both nitrification and denitrification processes. The removal rates of TN range from 0 – 15.4% and were lower compared to values reported for constructed wetland ranges (40 – 55%) by Vymazal (2007). This could be because of the release of nitrogen from surface soil as the soil of the restored wetland was

found higher in nitrogen concentration in comparison to a referenced natural wetland soil. These results are in agreement with Whitehead et al. (2006) and Krause et al. (2008) who showed that the removal of N declined due to increasing soil release of this element. The removal rates of $\text{NO}_3\text{-N}$ were between 3.5 – 18.4%. These rates were low compared to other natural and restored wetlands (Reddy and Delaune 2008) and the reason is probably because there was low $\text{NO}_3\text{-N}$ loading and low temperature to support nitrification as temperature was found to have a positive correlation to $\text{NO}_3\text{-N}$ in the restored wetland. But as the plants get mature it is expected that there will be better nitrification-denitrification in the site. The results in this study for N removal are below those that were obtained by other restored and constructed wetlands with similar sizes (Tab. 4).

Restoration Effects – Phosphorus Removal

The removal rates for TP ranged from -10.8 to 26% and 2.8 to 32.4 for SRP respectively. These low removal rates could be attributed to P release after reflooding and the decrease in redox and subsequent release of Fe-bound P as well as release of microbial P (soil data of the site; Aldous et al. 2005; Van Dijk et al. 2004). Flooding may have also cause large quantities of nutrients to flow off the fields, far beyond the removal capacity of the wetland. Flooding in the wetland caused reduced retention of nutrients which was also the case with Mitsch et al. (2005) who showed that SRP retention declined when a 1 hectare restored wetland received pulse water inflow as opposed to more constant flow. Similarly, Fink and Mitsch (2007) also showed decreased P retention due to spring and early summer storms while assessing a 1.2 hectares wetland. Other studies indicated that TP removal ranges between 40% and 60% in wetlands, depending on type and inflow loading (Vymazal et al. 2007). Even though there was export of P observed in the site, the results of P removal rates show that there was a marginal effect of seasonality on P removal probably because there was little adsorption of soluble phosphorus to roots and peats during the dry season. The results in this study for P removal are below those that were obtained by other restored and constructed wetlands with similar sizes (Tab. 4).

Restoration Effects – Soil properties

The organic matter (OM) of the natural wetland was relatively higher than the restored and degraded wetlands. This can be attributed to the waterlogged soil condition in the natural wetland that favored the growth and decomposition of macrophytic plants. There was fluctuating water condition in the restored wetland. Sahrawat (2004) reported that there is preferential accumulation of organic matter in waterlogged soils compare to well-drained soils. Additionally, the less dense vegetation cover may have also contributed to a reduction in the organic matter of the restored. McGeehan (2012) reported that the humus content of a soil is dependent primarily on the quantity of plant material per unit area that reaches the soil and the rate of decomposition. It is also possible that OM could have been lost due to the grading and scraping of surface soil horizons that occurred during the course of restoration to fill ditches and create microtopography.

Although, Nitrogen (N) and Phosphorus (P) were relatively higher in the restored wetland than the natural wetland, the concentrations of N and P fell within the same ranges. The source of N and P could have been from extra inputs from fertilizers in agricultural fields adjacent to the restored wetland and pollution runoff from a garbage collection point nearby. This was contrary to a study by Moreno-Mateos et al. (2012) that discovered Nitrogen storage remained significantly lower in restored wetlands for 30 years after the wetlands were restored or created. Similarly, results from studies by Lawrence and Schlesinger (2001) and Smil (2000) found that total phosphorus decreased only slightly in restored or created wetlands and did not show significant differences with reference wetlands. They attributed the lack of variation in phosphorus to more conservative cycling by phosphorus (lack of exchange with the atmosphere).

Management Implications and Conclusions

In this study we found unimpressive nutrient removal rates for $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$, TN, SRP and TP in a restored wetland monitored over one period of wet and dry season in Wakiso district, Uganda. But there was little water quality benefits observed when nutrient fluxes were calculated across the seasons. The retention time in the wetland was in a matter of days making single rain event to move water through the wetland in a matter of hours thus reducing the ability of the wetland to retain and transform nutrients especially in the wet season. The small size of the wetland coupled with additional P and N inputs from soil also contributed to the low nutrient removal rates. Soil properties in the restored wetland were found to be in similar ranges when comparison was made with properties of soil in a natural wetland with slight increases observed for N and P in the restored wetland. Soil results presented in this study should be treated with caution as soil assessment was not comprehensive and data collected were not sufficient to allow for speculation on restored wetland soil development. Soil data collected was for the purpose of understanding water nutrient behavior.

The monitoring of the restoration should consider management activities like periodic harvesting of shoots, distribution of water throughout the system, invasive species removal as well as the production and multiplication of macrophytic plants especially *Cyperus papyrus* in order to facilitate better removal capabilities. This study forms a baseline for understanding the ecology of restored wetlands in Uganda and will be helpful to policy makers, technicians and opinion leaders in designing future restoration projects.

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