Journal of Biophysical Chemistry, 2024, 15, 1-24
https://www.scirp.org/journal/jbpc
ISSN Online: 2153-0378
ISSN Print: 2153-036X

Effects of Papyrus Plants (*Cyperus papyrus*) on the Physicochemical Parameters and Nutrient Levels of Water and Sediments in Yala Swamp Wetland in Western Kenya

Violet Achieng Orodo[1], Paul Otieno Abuom[1*], Emmanuel Amukohe Shikanga[2], Elly Tetty Osewe[3], Douglas Nyambane Anyona[1], Fredrick Mhina Mngube[4], Stephen Adongo Odongo[5]

[1]Department of Environmental Studies, Maseno University, Kisumu, Kenya
[2]Department of Chemistry, Maseno University, Kisumu, Kenya
[3]Department of Physical and Biological Sciences, Murang'a University of Technology, Murang'a, Kenya
[4]Wetlands International, Dar es Salaam, Tanzania
[5]Department of Physical Sciences, Jaramogi Oginga Odinga University of Science and Technology, Bondo, Kenya
Email: *abuompo@yahoo.com

How to cite this paper: Orodo, V.A., Abuom, P.O., Shikanga, E.A., Osewe, E.T., Anyona, D.N., Mngube, F.M. and Odongo, S.A. (2024) Effects of Papyrus Plants (*Cyperus papyrus*) on the Physicochemical Parameters and Nutrient Levels of Water and Sediments in Yala Swamp Wetland in Western Kenya. *Journal of Biophysical Chemistry*, **15**, 1-24.
https://doi.org/10.4236/jbpc.2024.151001

Received: January 7, 2023
Accepted: February 20, 2024
Published: February 23, 2024

Abstract

Yala swamp wetland is the largest fresh water wetland ecosystem in Kenya supporting a broad biodiversity. It comprises of River Yala, the Yala swamp, Lakes Kanyaboli, Namboyo and Sare, and a portion of Lake Victoria neighboring the swamp. Approximately 2300 ha of land have been reclaimed and has been used for large-scale agriculture resulting in mass destruction of papyrus to create room for framing. Papyrus are known to be important in phytoremediation but despite this role information is limited, lacks supportive evidence and the empirical aspect on the levels of these pollutants in relation to the papyrus biomass is limited. The study is aimed at determining the effects of *Cyperus papyrus* on the water and sediment quality in Yala Swamp wetland. Six sampling sites were purposefully selected to monitor the variations of the physicochemical parameters (temperature, dissolved oxygen: DO, pH, biological oxygen demand: BOD, total suspended solids: TSS, turbidity, electrical conductivity: EC and total dissolved solids: TSS) and the levels selected nutrients (phosphorus and nitrates) in water and sediments as River Yala flows through Dominion Farms, Lake Sare which surrounded by *Cyperus papyrus* and finally into Lake Victoria. The samples were collected in triplicates during the wet and dry seasons (May and September 2015 respectively). The physicochemical parameters were measured *in situ* using a Hydrolab muiltimeter while the nutrients were analyzed using UV/Vis spectroscopy. Statistical analysis was done using SAS V9.0 software. The mean temperature was 26.19˚C ± 0.71˚C, DO: 3.72 ± 1.02 Mg/l, BOD: 3.9 ± 0.32 Mg/l, pH: 7.52 ± 0.17, TDS: 109 ± 86.33, EC: 173.26 ± 13.8 μS/cm, TSS: 12.42 ± 18.51 Mg/l and Turbidity: 12.29 ± 10.03 NTU. The values varied significantly at $P < 0.05$ among all the sites. The results show that papyrus is useful in maintaining the required levels of physicochemical parameters. The study will assist in conservation of the papyrus to help phytoremediate pollutants from Dominion farms and the adjacent farms in order to have ecologically sound wetland.

Keywords

Adsorbing Contaminants, Phytoremediation, Conservation, *Cyperus papyrus*

1. Introduction

Access to safe water is a fundamental need and basic human right [1]. It is important to constantly protect and control the quality of water. Wetlands around the globe are being modified, reclaimed and overexploited due to high levels of resource consumption, land conversion or upstream developments that alter the quality and flow of water that feeds into them [1]. The forces are so intense that many wetlands such as Nakivubo Wetland in Uganda and Yala Swamp in Kenya have previously been reported to be heavily degraded [2]. Geita wetland in Uganda has been converted to rice fields where accidental release of agrochemicals is common [3].

In Yala swamp agricultural activities have intensified leading to the destruction of *Cyperus papyrus* species with the biggest contributor being Dominion farms. Papyrus is a staut, aquatic perennial rhizomatous sedge that grows up to 3.5 m in height naturally in tropical and subtropical areas in swamps and along margins of Lakes and Rivers [4] and [5]. The roots are tough with numerous rootlets, the culms are erect and roundly trigonomous, smooth and 15 - 45 mm in diameter, photosynthetic, contain a solid pith and white light brown in colour. The leaves are alternate, have reduced sheathing and reddish blackish brown in colour when young. The inflorescence looks like an umbel, hemispherical when young. They can be browsed or cut for livestock feeding, used to make furniture, mats, baskets, handicrafts, roofing material and boat construction [6]. Plants also add oxygen, providing a physical site of microbial attachment to the roots generating positive conditions for microbes and bioremediation. In Yala swamp there is lack of scientific information relating the role of papyrus to its water cleaning role which necessitates this study.

Although studies have been conducted on the water quality of Lakes Kanyaboli and Namboyo which are also part of Yala Swamp Ecosystem, e.g. by [7], information on the role of papyrus plants on improving water quality specifically the water quality parameters of Lake Sare is limited. This scientific data on physicochemical parameters is necessary order to establish the phytoremediation role of papyrus plants. This was achieved by taking water and sediment samples from six sampling sites in different geographic locations along the flow channel of River Yala in Yala swamp and they constituted areas with the papyrus reeds and those without.

2. Materials and Methods

2.1. Sampling

Sampling of water, sediments and *Cyperus papyrus* was done in May 2015 for the wet season and in October 2015 for the dry season in the River Yala wetland. Six sampling sites lying between 0˚02'25"S; 034˚03'42"E and an altitude of 1140 m above sea level were selected purposefully following the direction of flow of water in River Yala through Dominion Farms, then through Yala Swamp (dominated with papyrus plants) and then through Lake Sare (also dominated with papyrus plants) and finally at the entry of water into Lake Victoria (**Figure 1**).

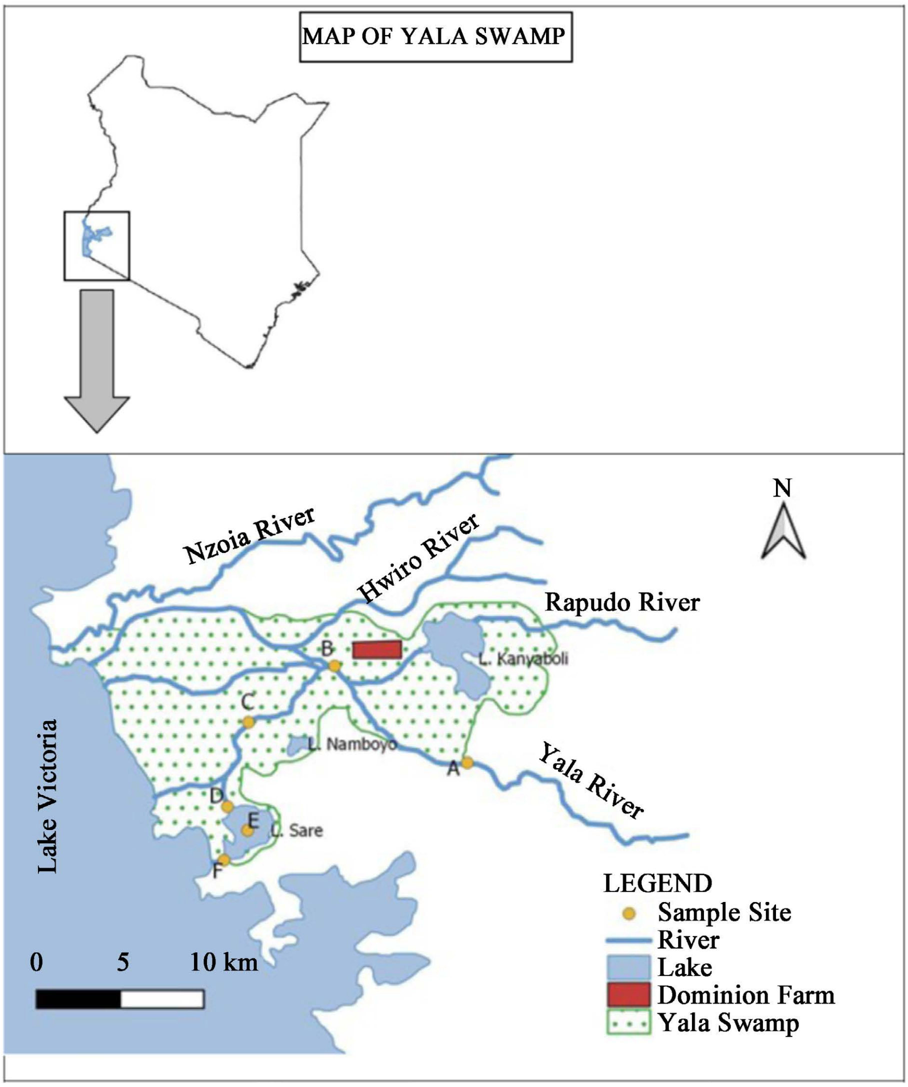

Figure 1. A skech map of the Yala swamp wetland showing sampling sites.

The sampling sites were, Station A (at the entry of River Yala into Dominion farms: the control), Station B (at the entry point of River Yala from Dominion farms into Yala Swamp, Station C (within the Yala Swamp approximately 3 km to Lake Sare and is dominated with papyrus plants), Station D (at the exit of Yala Swamp into Lake Sare also dominated by papyrus plants), Station E (at the center of Lake Sare about 3 km from the shores) and Station F (the lower part of Lake Sare just before it empties its waters into Lake Victoria). Sampling was done in triplicate for each set of samples in a location. Water samples were collected using plastic amber bottles, which were put in a cooler box at 4˚C before transferring to the laboratory for analysis. Sediment and Papyrus reed sample were also collected in plastic and transported to the laboratory for analysis.

2.2. Determination of Water Quality Parameters

The physico-chemical parameters of water were determined by taking *in situ* measurements of electrical conductivity (EC), pH, turbidity, temperature, total dissolved solids (TDS) and dissolved oxygen (DO) in Stations A-F in triplicate using a Hydrolab multimeter model (YSI 556 MPS Multimeter, USA). The Biological oxygen demand (BOD) for water samples was determined by getting the difference between the DO values of samples immediately after collection and the DO values of samples after incubation at 20˚C for five days. Total suspended solids (TSS) for each water sample were determined by filtering 50 ml of water through a pre-weighed standard glass-fiber filter. The residue retained on the filter was dried to a constant mass in an oven at 105˚C for 1 hour then cooled in a desiccator. The mass of total suspended solids in mg was determined according to Equation (1).

$$\text{Total Suspended Solids/L} = \frac{(A-B)\times 100}{\text{Sample volume}(\text{mL})} \tag{1}$$

where:

A = weight of filter + dried residue (mg),

B = weight of filter, (mg)

L = vol in litres

2.3. Data Analysis

Statistical analysis of data was done using SAS V9.0 software and Microsoft excel version 2010. One-way ANOVA without replication to determine significant differences between the values obtained in the different stations. Duncan Multiple Range Test (DMRT) was used post hoc separation of means to find significant differences in means. Student's t-test was used to establish the significant difference of all the parameters under study in the wet and dry season.

3. Results and Discussion

The data obtained from the analysis of the physicochemical parameters of water (Temperature, pH, DO, conductivity, turbidity, TDS, TSS and BOD) from the different sampling sites during the rainy and dry seasons are summarized in Table 1 and Table 2.

3.1. Temperature

The temperature of the different stations ranged from 24.0˚C ± 0.1˚C to 29.0˚C ± 0.7˚C in the dry season and 23.6˚C ± 0.1˚C to 29.0˚C ± 0.3˚C in the wet season. In general, with the exception of Station D, in which the temp in the dry season was not significantly different from that in the wet season ($P < 0.05$). The temperature obtained during the dry season for each station was higher than the corresponding temperature of the dry season. The mean temperature levels varied between the different sampling sites one-Way ANOVA, $F_{(5,11)} = 5.2920$, $P < 0.03$). The lowest temperature level (23.79˚C ± 0.26˚C) recorded at the entrance of River Yala to Dominion farms (station A) and the highest temperature level (28.99˚C ± 0.44˚C) recorded at the exit of Yala Swamp to Lake Sare (Station D). Lower temperatures were recorded in River Yala at station A (entrance of River Yala to Dominion farms) (23.79˚C ± 0.26˚C) could be because of the rigorous water movement and turbulences of the waters as it meets obstacles like stones and twigs which bring about a cooling effect. At station B (exit of River Yala from Dominion farms) the temperatures were higher (26.60˚C ± 1.98˚C) and this could be because the waters here were flowing from Dominion farms where a lot of pollutants had been introduced.

The waters were different in colour brown to black and not as clear as that of station A and the speed of water was also slow with no turbulence and the sediments had a foul smell in some sections [8], reported that the high water temperature could result from exothermic reactions of pollutants that influence the

Table 1. A summary of the physico-chemical parameters of water measured *in situ* in the selected sites in the River Yala wetland during the wet and dry seasons.

Parameters Sites	Temperature ˚C		pH		DO (mg/L)		Conductivity (µs/cm)		Turbidity (NTU)	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Station A	24.0 ± 0.1^{A}	23.6 ± 0.1^{A}	7.6 ± 0.1^{B}	7.4 ± 0.1^{B}	6.0 ± 1.1^{A}	4.1 ± 0.4^{A}	81.9 ± 0.2^{E}	84.7 ± 2.6^{D}	28.8 ± 1.3^{AB}	18.5 ± 3.4^{A}
Station B	28.0 ± 0.6^{B}	25.2 ± 0.4^{B}	7.4 ± 0.1^{BC}	7.4 ± 0.1^{B}	4.2 ± 0.1^{C}	1.6 ± 1.2^{C}	126.0 ± 1.7^{B}	309.3 ± 18.0^{B}	31.8 ± 3.5^{A}	12.8 ± 0.3^{B}
Station C	26.3 ± 1.3^{B}	24.6 ± 1.0^{C}	8.0 ± 0.5^{A}	7.6 ± 0.3^{AB}	3.1 ± 0.8^{D}	1.5 ± 0.6^{C}	448.8 ± 3.7^{A}	424.3 ± 10.7^{A}	17.4 ± 4.1^{C}	7.3 ± 4.5^{C}
Station D	29.0 ± 0.7^{B,C}	29.0 ± 0.3^{A}	7.3 ± 0.2^{C}	7.5 ± 0.2^{AB}	5.2 ± 0.5^{B}	2.7 ± 0.7^{B}	103.4 ± 4.4^{C}	103.9 ± 2.9^{C}	27.9 ± 2.9^{B}	0.80 ± 0.5^{D}
Station E	25.8 ± 0.2^{B,D}	27.3 ± 0.2^{B}	7.4 ± 0.1^{CB}	7.7 ± 0.2^{A}	5.0 ± 0.1^{BC}	3.9 ± 0.4^{A}	88.8 ± 0.9^{D}	106.0 ± 3.0^{C}	1.4 ± 0.1^{D}	0.01 ± 0.01^{D}
Station F	25.6 ± 0.2^{B,D}	25.9 ± 0.4^{C}	7.5 ± 0.1^{BC}	7.5 ± 0.1^{AB}	4.4 ± 1.0^{BC}	2.8 ± 0.4^{B}	88.6 ± 0.6^{D}	104.1 ± 0.8^{C}	1.3 ± 0.5^{D}	0.01 ± 0.004^{D}

Each value represents mean of triplicate measurements ± standard deviation.

adsorption of hydrocarbons in soil. At Yala Swamp (station C) and the entrance of River Yala to Lake Sare (station D), the temperatures were higher with D having the highest mean temperature (28.99˚C ± 0.04˚C). These sites were dominated by papyrus plants and the water velocity was very low. The high temperature could also be attributed to decrease in depth of water as reported by [9], who observed that the waters can spread in a large area due to the papyrus as obstacles and this would allow heat to penetrate the sand and consequently raise the temperature of water. [8], also observed that a wetland with high vegetation density will correspond to low flow rate. For this reason, most of the pollutants from Dominion farms settled here some being trapped by the papyrus roots and more reactions took place leading to the increased temperatures. Additionally, an increase in photosynthetic processes of aquatic plants and algae also increase water temperature as observed by [10]. The temperatures then reduced at Lake Sare (station E, 26.54˚C ± 1.07˚C) and the entrance of Lake Sare to Lake Victoria (station F, 25.72˚C ± 0.19˚C) and this could be because most of the pollutants had been broken down and some diluted thus no further reaction was taking place. Physiochemical water quality parameters, temperature included, are influenced by human activities and consequently the health of the population. Hence it is necessary to quantitatively assess the characteristics of river water. The traditional method of water quality assessment involves analyzing the chemical parameters and comparing them with existing standards [11].

In general, there were no significant differences in the mean temperature levels in the two seasons (Student's t-test, P = 0.43785). The slight difference between the dry and wet season mean temperature values could be attributed to the cooling and diluting effects of rain water. According to [12], during the wet season increased water inflow could result in lower water temperature and increased D.O values. Similarly, according to [13], low water temperatures could be due to increased water volume from rain water and decreased penetration of light rays due to deposition of silt and suspended materials. The findings of this study are also in agreement with a study by [14], in sections of Asa River in Nigeria that had mean temperature ranges of 25.04˚C to 30.13˚C. The mean temperatures for rainy and dry seasons were between 28.22˚C ± 0.96˚C and 24.60˚C ± 0.21˚C respectively. A similar study by [14], at Ishasha River and Lake Edward in Uganda had temperature ranges from 22.62˚C to 23.8˚C in the sampling sites. [15], in the same study area *i.e.* Yala Swamp obtained a mean temperature value of 27.02˚C. This is higher than the values obtained in this study both in the dry and wet seasons *i.e.* 26.45˚C ± 0.45˚C and 26.22˚C ± 0.4˚C respectively. This could be because at that time reclamation activities were still at a lower scale and much of the papyrus plants had not been interfered with and as mentioned earlier by [10], increase in photosynthetic processes of aquatic plants and algae also increase water temperature. The average temperatures for all the sampling sites were less than 40˚C which depicts a temperature range that is supportive of good surface water quality and survival of plants and animals as reported by [16].

3.2. Conductivity

Conductivity levels along the various sampling stations in River Yala, Yala Swamp and Lake Sare varied significantly (One-Way ANOVA, $F_{(5,35)} = 5628$, $P < 0.0001$). The highest value 436.51 ± 17.3 µS/cm was recorded at Yala Swamp (Station C) and lowest value 83.28 ± 1.98 µS/cm recorded at the entry of River Yala to Dominion farms (station A).

The permissible conductivity limit for domestic water supply is 200 µS/cm. Highest values were recorded at Yala Swamp (station C. 436.51 ± 51 µS/cm) where the pollutants first settle within the papyrus plants. The second highest value was also recorded at the exit of River Yala from Dominion farms (station B, 226.6 ± 12.20). This station receives most of the pollutants from Dominion farms which join the River water and they are later transferred to station C (Yala Swamp). The pollutants probably are the reasons behind the high conductivity levels. The high levels also indicate that the waters have a high concentration of electrolytes and dissolved solids since according to [10], EC of water can be termed as the total count of dissolved salt or as the forecaster of the individual ions. The conductivity levels reduce from the exit of Yala Swamp to Lake Sare (station D, 103.62 ± 0.33 µS/cm). This could be because most of the pollutants are absorbed by the papyrus plants and some decompose and change into other forms that are utilized by microorganisms.

The variation in electrical conductivity is closely According to [17], the variation and increase in electrical conductivity is closely dependent on the amount and mobility of charger carrier. This is so especially when a lot of pollutants dissolve forming ions. The variation in electrical conductivity is closely dependent on the amount and mobility of charge carrier.

The levels further reduce to Lake Sare (station E, 97.17 ± 11.8 µS/cm) and station F (the entrance of Lake Sare to Lake Victoria) had the least value (96.38 ± 10.9 µS/cm) after station A (83.28 ± 1.98 µS/cm) which is attributed to the papyrus plants. The nutrients that get into the waters of River Yala from Dominion Farms could be contributing to high conductivity levels in station C (Yala Swamp). The immense cutting and burning of the papyrus plants to create room for agriculture could cause increase in temperatures which further increase EC. Station A had the lowest level of conductivity (88.28 ± 1.98 µS/cm) could be because it is less polluted hence has less concentration of electrolytes.

In the two seasons there were no significant differences in conductivity (Students t-test $P = 0.3389$). The slight higher conductivity values in the wet season could be because according to [18], water bodies are recharged during the rainy season and the salts and nutrients are transported to the water bodies that increase conductivity levels. This could also be because at such times agricultural activities are at their peak which includes the use of herbicides, pesticides and fertilizers which later find their way in water runoff and increase the levels of EC.

Station B (River Yala after leaving Dominion Farms) had the highest conductivity value in the wet season (309.3 ± 2.9 μS/cm). This could be because it receives a lot of pollutants from Dominion Farms and as mentioned earlier it is during this season that agricultural activities are intensive. These pollutants dissolve forming ions which eventually increase conductivity levels and according to [19], a higher conductivity reflects higher water pollution. More so land use activities like spraying of crops to control pests and weeds or fertilizers increase the chloride, nitrate and phosphate levels which are known to also increase the conductivity levels. In the same station B the conductivity levels in the dry season are low (126.0 ± 1.7 μS/cm). This is attributed to the fact that the water levels are lower in this season hence low ions and also agricultural activities are fewer hence less pollutants are introduced to the water.

3.3. pH

The pH levels varied in the sampling stations (one-Way ANOVA, $F_{(5,36)} = 10.985$, $P < 0.001$). Station C (Yala Swamp) was significantly different from all other stations and had highest mean pH value 7.86 ± 0.30 and lowest value 7.38 ± 0.08 was recorded at the exit of Yala Swamp to Lake Sare (station D).

In most natural waters the pH ranges between 6.5 and 8.5 [20]. In this study the mean pH values ranged from 7.3 to 8.0 which indicate that they were within the permissible required range. The stations were slightly alkaline with the site within the papyrus reeds (station C), being the most alkaline (7.86 ± 0.30). Alkalinity is an indication of amount of carbonates and bicarbonates that shift the equilibrium producing hydroxyl ions. According to [21], pollutants can raise the amounts of carbonates and bicarbonates in water which explains the alkaline levels in the study area especially at station C (Yala Swamp) with pH level 7.86. This could be because of the pollutants coming from Dominion farms. Other contributors of alkaline pH are phosphorus and nitrogen containing compounds and from the study these elements were detected to some extend which was probably the cause of the alkaline conditions. The exit of Yala Swamp into Lake Sare (station D) had the lowest pH (7.38 ± 0.08). This could be because the station was dominated by papyrus reeds where a lot of biochemical processes between organic and inorganic wastes were taking place some of which produce weak acids that lower pH.

Low pH could be attributed to enhanced ammonification and nitrification processes that result to decay. Reduction in pH may also be due to carbon dioxide released by bacterial breakdown of organic wastes [22]. In this case the gases were found in the papyrus debris. This gas combines with water to form weak carbonic acid that lowers pH [22].

The pH levels in the study had the same mean levels for both seasons as indicated in **Table 1** (7.5 ± 0.2). However, in some stations like station C (Yala Swamp) the mean pH value was very high in the dry season compared to the wet season. This could be because during the dry months an increase in pH of a water body is associated with photosynthetic activities which increase uptake of nutrients, a decrease in rainfall volume and an increase in water for irrigation resulting in unstable diurnal pH curve. Station C (Yala Swamp) was dominated by Papyrus reeds hence it is probable that the high photosynthetic activities of the reeds would increase the pH.

The pH of water reduced after leaving the papyrus reeds which indicates that they play a role in improving pH. The seasons did not have an effect on pH values as indicated by Student's t-test P = 0.9361. However, in some stations like station C (Yala Swamp) the mean pH value was very high in the dry season compared to the wet season. This could be because during the dry months an increase in pH of a water body is associated with photosynthetic activities which increase uptake of nutrients, a decrease in rainfall volume and an increase in water for irrigation resulting in unstable diurnal pH curve. Station C (Yala Swamp) was dominated by Papyrus reeds hence it is probable that the high photosynthetic activities of the reeds would increase the pH. The pH of water reduced after leaving the papyrus reeds which indicates that they play a role in improving pH.

3.4. Dissolved Oxygen

The values of Dissolved Oxygen varied between the sampling stations one-Way ANOVA, $F_{(5,36)} = 10.98527$, $P < 0.0001$).Duncan Multiple Range Test further established that the mean DO value for station A (entry of River Yala to Dominion farms) was significantly different from all other stations and had the highest value of 5.10 ± 1.412 Mg/l. The lowest value 2.31 ± 1.12 Mg/l recorded at Yala Swamp (station C). Dissolved Oxygen varied between the sampling stations one-Way ANOVA, $F_{(5,36)} = 10.98527$, $P < 0.0001$).

DO is among determining factors for the survival and growth of aquatic organisms. In this study DO values were highest in station A (Entrance of River Yala into Dominion farms) 5.10 ± 1.41 Mg/l. This could be attributed to the fact that the water is less polluted with organic matter and is in constant turbulence that promotes aeration which increases the oxygen levels. The waters in station B (exit of River Yala from Dominion farms) and C (Yala Swamp) had the least mean DO values 2.89 ± 1.87 Mg/l and 2.31 Mg/l respectively. This is possible because most of the contaminants released by Dominion farms were introduced in the water in station B (River Yala from Dominion Farms) making it to be loaded with organic matter which later would flow into the water within papyrus reeds (station C).

Some of the wastes would probably use up most of the oxygen in the processes of oxidation to form other products. The papyrus reeds trap most of these contaminants in the roots and create anoxic conditions. According to [23], the decreased water volume caused by the reeds result to increased water temperature which decreases the solubility of oxygen in water hence low DO. The low DO values could also be due to aerobic decomposition of plant materials within the reeds, nitrification and mineral surface aeration resulting from vegetation cover.

High organic waste load contribute to decreased DO concentrations and increased BOD levels since the wastes use a lot of dissolved oxygen during decomposition [24]. This is also in agreement with [25] who also had the opinion that low DO could possibly be due to increased organic load which requires a high level of oxygen for chemical oxidation and breakdown. In the two seasons there were significant differences in DO (Student's t-test P = 0.0007). The levels of DO were higher in the dry season than the wet season. This could be according to [26], increase in temperature and duration of bright sunlight which has an influence on the percentage of soluble gases (Oxygen and carbon (IV) oxide).

During dry season the intense sunlight seem to accelerate photosynthesis by phytoplankton, utilizing CO_2 and giving off oxygen. This finally increases the DO levels. The correlation of DO with water body gives direct and indirect information e.g. bacterial activity, photosynthesis, availability of nutrients, stratification e.t.c. [27]. In both seasons the levels of DO are lowest in Station C *i.e.* 3.1 ± 0.8 Mg/l and 1.5 ± 0.6 Mg/l in the dry and wet seasons respectively. This could be because according to [28], low dissolved oxygen levels could be attributed to reduced water speed or lack of turbulent water movements that could increase the oxygenation. Station C is dominated by papyrus reeds which reduces the water speed and turbulence.

Similarly, in both seasons the level of DO increased from Yala swamp (station C) to the exit of Yala Swamp to Lake Sare (station D) e.g. from 1.51 ± 0.57 Mg/l in wet season to 2.63 ± 0.70 Mg/l and from 3.10 ± 0.83 Mg/l in dry season to 5.21 ± 0.51 Mg/l. The exit of Yala Swamp to Lake Sare (station D) also contains papyrus reeds but receives waters that have been filtered in Yala swamp (station C). Wetland plants are reported to transfer photosynthetic oxygen to the rhizosphere thus boosting the oxygen concentration in the water column. This could be the reason for the increase in DO values in the two Stations *i.e.* D and E.

According to [12], during the wet season increased water volume could result in lower water temperature and increased DO values a situation that could increase photosynthesis. However, this is not the case from the results obtained in this study where DO values in the dry season are higher than in the wet season hence they disagree (**Table 1**). This could be because according to [29], dissolved oxygen is depleted through chemical oxidation and respiration by aquatic animals and microorganisms especially during decomposition of plant biomass and other organic materials. The quantities of these materials *i.e.* plant biomass and organic materials are higher in the wet season. The same sentiments are held by [28] that the decomposition of organic substances from the industries and urban centers contributes to the low levels of dissolved oxygen in the water.

3.5. Turbidity Levels

Turbidity values varied in the various sampling stations (one-Way ANOVA, $F_{(5,35)} = 41.00014$, $P < 0.0001$). Duncan Multiple Range Test (DMRT) further established that mean turbidity levels for station A (entrance of River Yala to Dominion farms) was significantly different from all other stat Turbidity is a measure of the degree to which water losses its transparency due to presence of suspended particulates and the more the TSS the murkier it seems and the higher the turbidity [30]. In station A, the levels were the highest 23.64 ± 7.34 NTU due to the fact that the waters were in motion with turbulence which increases re-suspension of sediments in the water column. This is in agreement with [31] that states that during high water flows, water velocities are faster which can stir up and re-suspend materials from the River bed causing higher turbidities. Also there are chances that turbidity is high due to the immense agricultural activities taking place in the catchment area that contribute to erosion, storm water runoff and industrial discharges. In station B (exit of River Yala from Dominion Farms) the motion is less making some of the materials to settle but turbidity is still high since waste materials from Dominion farms are added to the water column. In station C (Yala Swamp) turbidity reduces due to the presence of the reeds that increase the residence time and retention of suspended organic materials in their root mass. This also applies to station D (exit of Yala Swamp to Lake Sare). In station E (Lake Sare) and station F (entrance of Lake Sare to Lake Victoria) the turbidity levels are least since most of the materials settle and turbidity was lowest.

According to [30], a wetland with high vegetation will correspond to low flow rate and low turbidity value. The same opinion is also expressed by [12], that a wetland with high vegetation density will correspond to low flow rate and low turbidity values. This further explains the decrease in turbidity values as the water passes through the papyrus reeds in station C and D to get to stations E and finally F (**Table 1**). Turbidity for drinking water should not be more than 5 NTU or ideally below 1 NTU [20], This implies that the water in all the stations studied were unfit for human consumption except at Lake Sare (station E) and the entrance of Lake Sare to Lake Victoria (station F). There were significant differences in turbidity levels in the two seasons (Student's T-test $P = 0.0379$).

Turbidity levels were high in the dry season than wet seasons but they reduced from the entry of River Yala to Dominion Farms (station A) to the mouth of Lake Sare to Lake Victoria (station F). This observation in decrease in turbidity from stations A to F in both seasons could also be due to sedimentation as River Yala passes through the wetland which concentrates the ability of wetland to retain sediments. This is consistent with the findings of [32], that the most important role wetlands is that they increase the residence time of water, act as natural water purification systems, removing silts and absorbing nutrients and toxins. Which means that they reduce the velocity and thereby increase the sedimentation of particles and associated pollutants.

At station A, the turbidity levels were higher than in any other station in both seasons (**Table 1**) could be because according to [28], high turbidity in the sub catchments is a direct consequence of poor agricultural practices and lack of buffer zone along the River. Station A and B had relatively high turbidity levels in both seasons could be because as River Yala flows it could be carrying sediments and other particles from runoff. The same opinion is echoed by [33], that high turbidity could be associated with sediments resulting from soil erosion from farming activities and urban runoff pollution. The other reason could be that the water was in motion with turbulence which increases the amount of suspended materials.

According to [31], during high flows, water velocities are faster which can stir up and suspend materials from the river bed causing higher turbidities. In this study turbidity levels are lower in the wet season than the dry season contradicting this statement could be because the area is known to do irrigation using water from weirs and when opened the water velocity becomes much higher which increase turbidity. The high turbidity in the dry season in the study area could also be because most agricultural activities like clearing and ploughing of land in preparation for planting happen at that time which leads to production of a lot of suspended soil and dust in water. This could further be due to low water volume during the dry season compared to the wet season where dilution effect takes place as reported by [31]. Some solids also dissociate as pH decreases during the dry season. According to [34], turbidity in water is the measurement of suspended and colloidal particles in water with size greater than 0.15 - 0.2 μm. Both suspended matter and turbidity are indicators that reflect the coarsely dispersed particles in the water. This explains why it is high in the dry season.

The papyrus reeds could also be playing a role in reducing turbidity in the wet season. Additionally, wetlands are expected to have high water flow rates and have an increase in turbidity values during rainy seasons compared to dry seasons as observed by [34], which makes rainfall amounts an instrument in regulating physical parameters of a wetland ecosystem. But as mentioned earlier this is not the case in this study since other factors come in.

3.6. Biological Oxygen Demand

The BOD values did not vary significantly between the different sampling sites (one-Way ANOVA, $F_{(5,23)} = 1.349287$, $P = 0.289087$). The highest mean BOD value was recorded in station A (4.39 ± 1.54 Mg/l) and the lowest mean BOD value recorded at station D (3.71 ± 2.32 Mg/l). DMRT also established that the BOD values did not vary significantly in all the stations

BOD is a measure of the amount of oxygen removed from aquatic environments by aerobic micro-organisms for their metabolic requirements during the breakdown of organic matter (UNEP, 2006). In this study the highest BOD values 4.39 ± 1.54 Mg/l was obtained in station A (River Yala before getting to Dominion farms) (**Table 2**). According to [35], highest BOD could be due to a high influx of organic material resulting from rain water runoff and animal wastes as they drank water. This could explain the high BOD values at station A as animals from the community around the study area could be seen taking water and probably they would excrete their wastes in the process that would consequently increase BOD levels.

This is an indication of pollution which suggests that River Yala has other sources of pollutants and not just Dominion farms. The average BOD levels for the study area is 3.91 ± 0.32 Mg/l which further indicates that the area is polluted since according to [36], unpolluted waters typically have BOD values of 2 Mg/L O2 or less, whereas those receiving wastewaters may have values up to 10 Mg/l or more, particularly near to the point of wastewater discharge.

The BOD levels were low in almost all the stations during the wet season, with the highest value recorded was at station A (3.30 ± 0.76 Mg/l) and lowest at station C (2.08 ± 0.17 Mg/l). In the dry season the BOD values were higher compared to the wet season, with Lake Sare (station C) recording the highest value of 5.57 ± 0.12 Mg/l) and the exit of Yala swamp to Lake Sare (station D) the lowest (4.29 ± 0.1 Mg/l) (Table However there were significant differences in BOD levels in the dry and wet seasons (Student's t-test P = 0.02013).

In the dry season the exit of River Yala from Dominion farms (station B) had a high BOD value 5.56 ± 0.09 Mg/l (**Table 2**). This station receives a lot of pollutants from Dominion farms and according to [35], high BOD values could possibly be due to a high influx of organic material resulting from runoff and animal wastes. A study by [37], at River Yobe Nigeria had BOD values averaging to 2.77 Mg/l which are close to the findings in this study *i.e.* 2.55 ± 0.59 Mg/l in the wet season.

High BOD values indicate decline in DO since oxygen is being consumed by the bacteria for respiration leading to inability of other aquatic organisms to survive. Additionally, during the dry seasons, the water volume reduces which carries a low concentration of oxygen. Studies have shown that constructed wetland with similar conditions like Yala Swamp can reduce the concentrations of suspended solids, BOD, nitrogen, phosphorus and coliform bacteria often by 98% [38]. In the dry season there was a drastic drop in the BOD levels from Yala Swamp (station C, 5.34 ± 0.09 Mg/l) to the exit of Yala Swamp to Lake Sare (station D, 4.29 ± 0.1 Mg/l). This could be because the accumulated wastes within the papyrus reeds encourage high microbial activities to take place. These activities break down pollutants from Dominion Farms and organic substances

Table 2. The levels of biological oxygen demand, TSS and TDS determined in water in the selected sites in the River Yala wetland during the wet and dry seasons.

Sites	TDS (Mg/l)		TSS (Mg/l)		BOD (Mg/l)	
	Dry	Wet	Dry	Wet	Dry	Wet
Station A	56.4 ± 1.05^{C}	55.25 ± 1.68^{C}	0.71 ± 0.10^{D}	8.07 ± 2.61^{D}	5.49 ± 0.15^{AB}	3.37 ± 0.76^{A}
Station B	75.69 ± 3.41^{B}	199.96 ± 26.13^{B}	2.86 ± 0.18^{A}	95.5 ± 5.0^{A}	5.56 ± 0.09^{A}	2.03 ± 0.84^{B}
Station C	273.33 ± 8.96^{A}	273.83 ± 8.91^{A}	1.21 ± 0.07^{C}	12.23 ± 1.94^{C}	5.34 ± 0.09^{B}	2.08 ± 0.17^{B}
Station D	59.18 ± 3.11^{C}	67.37 ± 1.71^{C}	1.98 ± 0.04^{B}	20.86 ± 2.35^{B}	4.29 ± 0.10^{C}	2.63 ± 0.54^{AB}
Station E	56.09 ± 0.32^{C}	67.39 ± 1.50^{C}	0.53 ± 0.09^{E}	2.47 ± 0.35^{E}	5.57 ± 0.12^{A}	2.58 ± 0.69^{AB}
Station F	56.07 ± 0.33^{C}	67.88 ± 0.51^{C}	1.05 ± 0.18^{C}	1.39 ± 0.17^{E}	5.37 ± 0.04^{B}	2.63 ± 0.54^{AB}

which utilize most of the oxygen leading to systems with high BOD to have low dissolved oxygen concentrations. In this study the stations with high BOD values had low DO values e.g. in the exit of River Yala from Dominion farms (station B) and Yala swamp (station C) in the dry season had DO values of (4.2 Mg/l and 3.1 Mg/l) and high BOD values of (5.56 Mg/l and 5.34 Mg/l respectively). Recommended standard by WHO for BOD should be 1 to 2 Mg/l [38]. This shows that all the stations in this study area did not meet the right BOD standards.

The high levels of BOD in the dry season could be explained by [23], who noted that nutrient enrichment in streams and Rivers as a result of land use change accelerates litter breakdown rates by bacteria and fungi which eventually increases the BOD levels. Most of these activities like land preparation, planting, and addition of fertilizers take place in the dry season in this study area which justifies the findings of this study.

3.7. Total Suspended Solids

The values of TSS varied among the sampling sites (one-Way ANOVA, $F_{(5,23)} = 542.901$, $P < 0.0001$). The highest mean TSS value 49.18 ± 2.58 Mg/l was recorded at the exit of River Yala from Dominion farms (station B) and the least value 1.20 ± 0.09 Mg/l recorded at the exit of Lake Sare to Lake Victoria (station F). DMRT further established that the mean TSS level in station B was significantly different from any other station.

The high TSS levels in River Yala after leaving Dominion farms (station B) could be because of the many activities like farming and pollutants introduced into the waters as River flows in Dominion Farms which include materials like fertilizers, herbicides, fish feeds or runoff of loose soils from cultivated lands. As reported by [27], high TSS can result in high sediment supply, discoloration and unclear water appearance. This is exactly how the waters at the exit of River Yala from Dominion farms (station B) appeared. These materials then move to the papyrus reeds (Station C), where they settle and some are broken down by bacteria such that by the time the water gets to Lake Sare (station E) the TSS level is very low.

The high TSS levels could also be caused by coagulation of pollutants and chemicals from Dominion Farms due to chemical reactions. According to [39], Physical and chemical parameters of water may be affected downstream by aquatic plants that may be found in the wetland since they help help in removing inorganic chemicals and suspended solids from surface stream waters through absorption by plants within and natural filtration. This could also explain the reduction in the TSS levels from station C to D, E and F. The high TSS levels within the papyrus plants in stations C and D (6.87 ± 7.99 Mg/l and 11.21 ± 13.05 Mg/l respectively) could be because the pollutants and other materials are trapped within the roots of the papyrus plants which increase their levels due to accumulation. Afterwards the TSS levels reduce drastically in station E and F (1.52 ± 1.37 Mg/l and 1.20 ± 0.29 Mg/l respectively) which is attributed to the papyrus reeds. The slow motion of the water also encourages settling of sediments which further reduce TSS. The mass of water at stations E and F is also big which can also reduce TSS values by dilution effect. There were no significant differences in TSS levels in the two seasons (Students T-test P = 0.17422).

In the study the values of TSS were higher in the wet season than in the dry season. This could be because in the dry season there is a lot of sedimentation as the materials settle while in the wet season other natural processes like erosion, wind and flooding occur which spread the materials as a natural part of the environment as reported by [40], The role of the papyrus in reducing the levels of TSS is quite evident from the results as the levels reduce drastically as the waters pass through the swamp since the materials are trapped by the papyrus roots, some are utilized by the reeds and some just settle. Eventually the water that leaves the reeds is clearer with very low TSS. Studies by [9], at Chemelil constructed wetland in Kisumu and splash constructed wetland in Nairobi revealed drastic reduction in TSS levels *i.e.* from 1.10 Mg/l to 0.04 Mg/l and from 195.4 Mg/l to 4.7 Mg/l respectively. This also applies to this study whereby in both seasons the level of TSS drops as the waters pass through the papyrus plants.

3.8. Total Dissolved Solids

The TDS values varied between the sampling sites (one-Way ANOVA, $F_{(5,41)}$ = 1589.277, $P < 0.0001$). The highest mean value 273.58 ± 0.36 Mg/l was recorded at Yala Swamp (station C) and the lowest value 55.83 ± 0.81 Mg/l recorded at the entry of River Yala to Dominion farms (station A). Duncan Multiple Range Test further established that mean TDS value in station C was significantly different from any other station in the study area. TDS is a measure of the presence of dissolved salts. In this study the highest levels were recorded in Yala Swamp (station C). The high levels of TDS especially at station C could be because most of the pollutants introduced in River Yala from Dominion farms have been broken down by bacteria into a dissolved state increasing amount of ions in water and also accumulated in the swamp. Most of these dissolved pollutants are absorbed and utilized by the papyrus reeds which leads to a reduction in the levels as the water moves to Lake Sare as indicated in **Table 2**. According to [28], the occurrence of low TDS, could be ascribed to the provision of adequate vegetation cover around the farms that reduces the soil erosion within these sub-catchments. This is consistent with the findings of this study especially in station D that is occupied by numerous papyrus plants.

A study by [41], in Nyaruzinga wetland Uganda had TDS values ranging from 40.98 to 545.63 Mg/l. These results are higher than the findings of this study and could be because there are more agricultural activities in the wetland than in Yala Swamp. There were no significant differences in TSS levels in the two seasons (Students T-test P = 0.1875). In this study the values of TDS are higher in the wet season than in the dry season probably because a lot of agricultural activities takes place in the wet season including addition of fertilizers, use of herbicides to control weeds, use of lime to correct acidity and even the washing away of fish feeds by excess rain water. According to [42], non-point sources such as nutrients, pesticides, heavy metals and sediments are transported from land by atmospheric, surface water and ground water pathways. Such chemicals and organic materials could increase the TDS levels.

The low TDS recorded afterwards (in stations D, E and F) (**Table 2**), could be due to settling of silt and dissolved salts as reported by [43], that the settling of silt and dissolved salts in water bodies tend to lower TDS levels. Similarly, according to [44], to high levels of TDS are generally recorded in effluent discharge points and reduce downstream probably due to the Rivers self-cleansing capacity.

The wet season had high TDS values compared to the dry season in all the stations (**Table 2**). This could be because according to [45], in the wet season TDS increase due to runoffs from sediments and catchment watersheds that occurs when it rains. In both seasons the TDS levels are highest at station C (Yala Swamp). This could be because the water in station C comes from station B which contains a lot of wastes, contaminants and agro chemicals from Dominion Farms. According to [46], elevated levels of TDS can be closely linked to the industrial effluent from the factories and agrochemicals.

The levels later reduce as the water pass through the papyrus reeds in station D and the reducing trend goes on until it is least at stations E and F (**Table 2**). This could be because some of the dissolved solids are utilized by the papyrus plants. It can also be attributed to dilution effect. In the study, TDS values of the water were below the WHO and KEBS maximum allowable limits of 1000 $mg \cdot L^{-1}$ and 1500 $mg \cdot L^{-1}$ respectively with a mean of 96.126 $mg \cdot L^{-1}$ for dry season and 121.946 $mg \cdot L^{-1}$ thus safe for drinking. [46].

3.9. Nutrients

3.9.1. Seasonal Variation of Nitrate Levels in Water and Sediments

Data obtained from analysis of nitrate values in water and sediments in the dry and wet season are represented in **Table 3** below.

Nitrate levels in water did not show any significant variation during the wet season across the different stations (one-Way ANOVA, $F_{(5, 23)} = 2.01$, $P = 0.1264$. The highest value 2.2 ± 0.1 Mg/l was recorded at the entry of River Yala to Dominion farms (station A) and lowest value1.90 ± 0.2 Mg/l recorded at the exit of Yala swamp to Lake Sare (station D) and at the entry point of Lake Sare to Lake Victoria (station F).

The nitrate levels varied in the dry season across the different stations (one-Way ANOVA, $F_{(5,23)} = 335.0$, $P < 0.0001$). Nitrate values in water in the dry season were much lower than those recorded in the wet season with the highest mean 1.8 ± 0.02 Mg/l recorded at Lake Sare (station E) and the lowest value 1.4 ± 0.01 Mg/l recorded at Yala Swamp (station C) (**Table 3**). DMRT further established that there were significant differences in mean Nitrate values in water between all the stations in the dry and wet seasons except between station E in the dry season and E in the wet season (**Table 3**). There were significant

Table 3. Seasonal variation of phosphate levels in water and sediments in the River Yala Wetland.

Sampling sites	Nitrates in water (mg/l)		Nitrates in sediments (mg/l)	
	Dry season	Wet season	Dry season	Wet season
A	1.6 ± 0.01^{B}	2.2 ± 0.1^{A}	1.4 ± 0.1^{B}	1.4 ± 0.4^{B}
B	1.6 ± 0.01^{B}	2.1 ± 0.02^{A}	1.5 ± 0.3^{A}	2.01 ± 0.1^{A}
C	1.4 ± 0.01^{C}	2.1 ± 0.1^{A}	1.3 ± 0.2^{B}	2.04 ± 0.1^{A}
D	1.4 ± 0.02^{C}	1.9 ± 0.2^{A}	1.1 ± 0.1^{B}	2.2 ± 0.5^{A}
E	1.8 ± 0.02^{A}	2.1 ± 0.2^{A}	1.6 ± 0.1^{A}	1.7 ± 0.2^{B}
F	1.4 ± 0.03^{C}	1.9 ± 0.2^{A}	1.1 ± 0.1^{B}	2.0 ± 0.04^{A}
Mean	1.5 ± 0.02	2.1 ± 0.2	1.3 ± 0.15	1.89 ± 0.22

*Means with different superscripts in the same column are significantly different at P < 0.05 (Data analyzed by Duncan's Multiple Range Test). Note: A = Entry of River Yala to Dominion farms, B = River Yala as it leaves Dominion farms, C = within papyrus reeds, D = Exit of Yala Swamp to Lake Sare, E = middle of Lake Sare, F = Entry point of Lake Sare to Lake Victoria.

differences in the level nitrates in sediments in the two seasons. (Students t-test, P = 0.000249).

Nitrate levels in sediments varied across different stations in the wet season (one-Way ANOVA, $F_{(5,23)}$ = 8.44, P = 0.0003). The exit of Yala Swamp to Lake Sare (station D) recorded the highest value of nitrates in sediments (2.20 ± 0.5 Mg/l) while the entrance of River Yala to Dominion farms (station A) recorded the lowest nitrate value in sediments (1.40 ± 0.40 Mg/l). In the dry season the nitrate values in sediments also varied (one-Way ANOVA, $F_{(5,23)}$ = 13.24, P < 0.0001). The highest mean value recorded for nitrates in sediments 1.60 ± 0.1 Mg/l was at Lake Sare (station E) while the lowest value recorded 1.1 ± 0.10 Mg/l was at the exit of Yala Swamp to Lake Sare (station D) and at the entry of lake Sare to Lake Victoria (Station F) (**Table 3**). DMRT established that there was a significant difference in mean nitrate values in sediments between stations A in the dry season and station A in the wet season. This was similar to station B in the dry season and station B in the wet season. However, there was no significant difference in mean nitrate levels between the remaining stations in the dry and wet season. There were significant differences in the level nitrates in sediments in the two seasons. (Students t-test, P = 0.02498).

From the study the levels of Nitrates in water were higher in the wet season than in the dry season. This could be because most agricultural activities take place in the catchment area during the wet season like planting, addition of fertilizers or herbicides, liming among others, which increase the level of nitrates in the runoff. In the dry season such activities are less and the station within the papyrus reeds (station C) had the least Nitrate levels (1.4 ± 0.01 Mg/l) since the papyrus reeds and other plants utilize most of the nitrates in the waters to make proteins.

According to [47], seasonality in the concentration of nutrients, particularly in agricultural areas is common with peaks being recorded during high flow periods. This explains the high levels of nitrates in water in the wet season. High flows usually occur when fields lack vegetation cover and nitrate-nitrogen for instance gets easily leached from the soil. Inorganic nitrogen forms are subject to biological transformations that increase with increasing temperature [48]. Seasonality in nutrient levels can be attributed to the deposition in the sediments during low flow periods and resuspension and transportation during high flow periods. This explains the low nitrate levels in sediments during the dry season and high levels during the wet season.

According to [49], nitrogen in wetlands can also be removed by nutrient uptake of plants. The plants uptake nitrogen in the form of ammonium or nitrate, which is then stored in the plant in the organic form. This explains why in the dry season both in water and sediments the levels of nitrates reduced significantly in the waters within the papyrus reeds in stations C and D then afterwards the levels increase in station E that lacks the papyrus reed (**Table 3**). The levels thereafter again increase in station F that is also surrounded by papyrus reeds depicting that the reeds use up the nitrates for their growth and development. In the wet season the trend is similar in water but not in sediments could be because during such seasons the high volume of water may transport nutrients from other areas due to run off and settle in sediments leading to the higher levels recorded.

According to [50], and [51], wetlands have been demonstrated to be an effective means to attenuate nitrogen derived from diffuse water pollution by plant and periphyton uptake and microbial denitrification. From studies papyrus seems to promote greater nitrogen removal efficiencies through nitrification and denitrification rates of bacterial associated with its roots as reported by [49]. Optimum pH range for denitrification is reported to be between 7.0 and 8.5 [52], and it is highly temperature dependent with reaction rates significantly reduced at temperatures below 5˚C. In this study the pH values range between 7.3 to 8.1 and temperatures range between 23.60˚C to 29.05˚C which justifies the fact that denitrification is taking place.

In some wetlands, studies have shown that denitrification is the dominant nitrate removal mechanism [51], and [48]. However, microbial activity, which controls denitrification rates, can be reduced at low temperatures [53]. This is consistent with the findings of this study where the levels of nitrates are higher in the wet season than the dry season both in water and sediments since as explained denitrification rates are low at low temperatures and so more nitrates become available. Similarly, according to [51], in line with these seasonal differences in wetlands, nitrogen removal performance are widely reported with reduced rates measured at colder temperatures.

The high levels of nitrates in the rainy season in water is in agreement with [54], who concluded that nitrates are usually built up during dry seasons then the initial rains flush out deposited nitrate from near surface soils and nitrate level reduces drastically in sediments and increases in water as rainy season progresses.

3.9.2. Phosphates in Water and Sediments

Data obtained from analysis of phosphate values in water and sediments in the dry and wet season are represented in Table 4 below.

There were significant differences in mean phosphate levels in water in the various stations in the dry season (one-Way ANOVA, $F_{(5,23)} = 71.57$, $P < 0.0001$). In the wet season there were no significant variation in mean phosphate values in water across the different stations (one-Way ANOVA, $F_{(5,23)} = 2.32$, $P = 0.0855$). DMRT also established that there were significant differences in mean phosphate values between the stations in the dry season and in the wet season except between station B in the dry and B in the wet season and between station D in the dry and wet season (Table 4). There were no significant differences in phosphate levels in water in both seasons (Students t-test, $P = 0.1772$).

In sediments, Phosphate levels varied significantly across stations in the wet season (one-Way ANOVA, $F_{(5,23)} = 5.11$, $P < 0.0043$). In the dry season the values also varied significantly (one-Way ANOVA, $F_{(5,23)} = 164.06$, $P < 0.0001$). DMRT established that there were significant differences in mean phosphate value between the stations in the dry and wet season except between station A in the dry and wet season and station F in the dry and wet season (Table 4). There were also no significant differences in phosphate levels in water in both seasons (Students t-test, $P = 0.60674$).

According to [55], the sufficient supply of oxygen in favor of oxidation of elements in water e.g. Fe, Mn etc. enhances their absorption at sediment water

Table 4. Seasonal variation of phosphate levels in water and sediments in the River Yala wetland.

Sampling sites	Phosphates in water (Mg/l)		Phosphates in sediments (Mg/l)	
	Dry season	Wet season	Dry season	Wet season
A	0.10 ± 0.01^{C}	0.1 ± 0.03^{A}	0.09 ± 0.01^{B}	0.1 ± 0.03^{B}
B	0.58 ± 0.10^{A}	0.1 ± 0.03^{A}	0.05 ± 0.02^{C}	0.2 ± 0.13^{A}
C	0.04 ± 0.01^{D}	0.04 ± 0.01^{AB}	0.03 ± 0.01^{CD}	0.04 ± 0.01^{B}
D	0.29 ± 0.01^{B}	0.03 ± 0.02^{B}	0.27 ± 0.02^{A}	0.04 ± 0.01^{B}
E	0.02 ± 0.01^{D}	0.02 ± 0.001^{B}	0.02 ± 0.01^{D}	0.02 ± 0.01^{A}
F	0.01 ± 0.01^{D}	0.02 ± 0.002^{B}	0.09 ± 0.01^{B}	0.03 ± 0.01^{AB}
Mean	0.17 ± 0.01	0.05 ± 0.01	0.09 ± 0.01	0.07 ± 0.03

*Means with different superscripts in the same column are significantly different at $P < 0.05$. (Data analyzed by Duncan's Multiple Range Test). Note: A = Entry of River Yala to Dominion farms, B = River Yala as it leaves Dominion farms, C = within papyrus reeds, D = Exit of Yala Swamp to Lake Sare, E = middle of Lake Sare, F = Entry point of Lake Sare to Lake Victoria interphase and finally retards the release of phosphates to overlaying water. This explains the low mean phosphate levels especially in the wet seasons (**Table 4**) since the swamp is well oxygenated especially during this season with DO levels ranging from 3.10 to 6.09 Mg/l. During the dry season the mean levels of phosphates in sediments are higher than during the wet season as indicated in **Table 4**.

This is so because according to [56], the largest contribution of nutrients emanates from River flow and run-off, which constitute more than 50% with atmospheric contribution making 40%. This means that direct land activities mainly farming which mostly takes place in the dry season is responsible for high nutrient load which includes phosphates into the lake. Most run off take place during the rainy season and most papyrus reeds which create a buffering capacity have been destroyed in Yala Swamp to give room for farming.

In this study levels are quite low could be because of the presence of papyrus reeds that reduce their levels after utilizing them. This is evident as the levels reduce from the exit of River Yala from Dominion farms (station B) to the exit of Lake Sare to Lake Victoria (station F) especially in the dry season.

Phosphates also exist as orthophosphates and research has shown that the transport of Phosphates from agricultural fields occurs primarily via surface flow when the water flowing across the soil surface either dissolves and transports soluble Phosphorus or erodes and transports particulate Phosphorus [57]. This explains the higher levels of phosphates in water than in sediments in both seasons. In this study seasons did not affect the levels of phosphates in water and sediments (Students t-test, P = 0.177234 and P = 0.60674 respectively). Some large values presented in this table could probably be due to random error during collection of data but the judgment made conserving the results have this consideration in mind.

4. Conclusion

The papyrus plants showed the capacity of adsorbing and absorbing pollutants as evident from the reduction of levels physicochemical parameters nutrients from station B believed to be the source of pollutants through stations C and D dominated by papyrus plants and finally reduce to standard levels in station E and F. For this reason, it is important that they are conserved. Seasons also played a role on the levels of parameters in water. They were generally high in the dry season with a few exceptions like Nitrates which were higher in the wet season in both water and sediments. This probably is due to the high solubility levels of nitrates. A further study can be done on other parameters like chlorides, sulphates and other nutrients to find out their levels and assist in emphasizing the role of papyrus plants in adsorbing them.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] WHO (World Health Organization) (2000) Global Water Supply and Sanitation Assessment 2000 Report. World Health Organization, Geneva.

[2] Abila, R. (2002) Utilization and Economic Valuation of the Yala Swamp Wetland, Kenya. *The 2nd International Conference on Wetlands and Development*, Dakar, November 1998, 89-95.

[3] Fredrick, J.M., Fredrick L.M. and Raphael (2011) Environmental Quality and Fish Communities in Selected Catchments of Lake Victoria. *The Open Environmental Engineering Journal*, **4**, 54-65. https://doi.org/10.2174/1874829501104010054

[4] Popay, I. (2014) *Cyperus papyrus (*Papyrus) Invasive Species Compendium. CABI Publishing, Wallingford.

[5] Vaughan, G. (2011) *Cyperus papyrus* L. In: Brink, M. and Achigan-Dako, E.G., Eds., *PROTA* (*Plant Resource of Tropical Africa*), PROTA Foundation, Wageningen, 120-126.

[6] Johns, M.B., Kansiime, F. and Saunders, M.J. (2018) The Potential Use of Papyrus (*Cyperus papyrus* L.) Wetland as a Source of Biomass Energy for Sub-Saharan Africa. *GCB Bioenergy*, **10**, 4-11. https://doi.org/10.1111/gcbb.12392

[7] Romulus, A., Walter, S., Millicent, F.N., Dickson, O.O., Marta, B. and Alex, M. (2008) The Role of Yala Swamps in Conservation of Lake Victoria Region Haplochromine Cichlids. Evidence of Genetic and Trophic Ecology Studies. *Journal of Lakes and Reservoirs*, **13**, 95-104. https://doi.org/10.1111/j.1440-1770.2008.00366.x

[8] Odada, E.O., Olago, D.O., Kulindwa, K., Ntiba, M. and Wandiga, S. (2004) Mitigation of Environmental Problems in Lake Victoria, East Africa: Causal Chain and Policy Options Analyses. *AMBIO*: *A Journal of the Human Environment*, **33**, 13-23. https://doi.org/10.1579/0044-7447-33.1.13

[9] Oketch, M.A. (2002) The Potential Role of Constructed Wetlands in Protection and Sustainable Management of Lake Catchments in Kenya. Department of Environmental Science, Egerton University, Nakuru.

[10] Roleda, M.Y. and Hurd, C.L. (2019) Seaweed Nutrient Physiology: Application of Concepts to Aquaculture and Bioremediation. *Phycologia*, **58**, 552-562. https://doi.org/10.1080/00318884.2019.1622920

[11] Noori, R., Berndtsson, R., Hosseinzadeh, M., Adamowski, J.F. and Abyaneh, M.R. (2019) A Critical Review on the Application of the National Sanitation Foundation Water Quality Index. *Environmental Pollution*, **244**, 575-587. https://doi.org/10.1016/j.envpol.2018.10.076

[12] Ndubi, D., Oyaro, N., Githae, E. and Afullo, A. (2015) Determination of Physico-Chemical Properties of Sources of Water in Narok North Sub-County, Kenya. *International Research Journal of Environmental Sciences*, **4**, 47-51.

[13] Ombaka, O. and Gichumbi, J.M. (2012) Investigation of Physico-Chemical and Bacteriological Characterization of Water Samples from Irigu River, Meru South, Kenya. *International. Journal of Scientific and Engineering Research*, **3**, 48-52.

[14] Ogundiran, M.A. and Fawole, O.O. (2014) Assessment of the Impacts of Industrial Effluent Discharges on the Water Quality of Asa River, Ilorin, Nigeria. *Journal of Environmental Science*, *Toxicology and Food Technology*, **8**, 80-98. https://doi.org/10.9790/2402-08718098

[15] Gichuki, F.N. (2003) A Review of Wetland Research in Lake Victoria Basin, Kenya: Analysis and Synthesis. Report, SIDA-SAREC, Nairobi.

[16] WHO (World Health Organisation) (2011) Guidelines for Drinking Water Quality. 3rd Edition, World Health Organisation, Geneva.

[17] Mohd, K.O. and Azizah, H.A. (2015) Conductivity and Ionic Mobility Studies on Li_2WO_4-LiI-Al_2O_3 by EIS and NMR Techniques. *Jurnal Teknologi*, **75**, 39-44. https://doi.org/10.11113/jt.v75.5170

[18] Anyona, D.N., Dida, G.O., Abuom, P.O., Onyuka, J.O., Matano, A.S., Kanangire, C.K. and Ofulla, A.V.O. (2014) Influence of Anthropogenic Activities on Microbial and Nutrient Levels along the Mara River Tributaries, Kenya. *Eurasia Journal Biosciences*, **8**, 1-11. https://doi.org/10.5053/ejobios.2014.8.0.1

[19] Jayasiri, M.M., Yadav, S., Dayawansa, N.D.K., Propper, C.R., Kumar, V. and Singleton, G.R. (2022) Spatio-Temporal Analysis of Water Quality for Pesticides and Other Agricultural Pollutants in Deduru Oya River Basin of Sri Lanka. *Journal of Cleaner Production*, **330**, Article ID: 129897. https://doi.org/10.1016/j.jclepro.2021.129897

[20] WHO (World Health Organization) (2007) pH in Drinking Water in Guidelines for Drinking Water Quality. 3rd Edition, World Health Organisation, Geneva.

[21] Rayaroth, M.P., Aravind, U.K. and Aravinakumar, C.T. (2017) Ultrasound Based AOP for Emerging Pollutants: From Degradation to Mechanism. *Environmental Science and Pollution Research*, **24**, 6261-6269. https://doi.org/10.1007/s11356-016-6606-4

[22] Asuquo, J.E. and Etim, E.E. (2012) Physicochemical and Bacteriological Studies of Selected Bore Hole Water in Uyo Metropolis in Akwa Ibom State. *International Journal of Modern Chemistry*, **2**, 7-14.

[23] Allan, J.D. (2004) Landscapes and Riverscapes: The Influence of Land Use on Stream Ecosystems. *Annual Review of Ecology*, **88**, 1030-1040. https://doi.org/10.1146/annurev.ecolsys.35.120202.110122

[24] Busulwa, H.S. and Bailey, R.G. (2004) Aspects of the Physicochemical Environment of the Rwenzori Rivers, Uganda. *African Journal of Ecology*, **42**, 87-92. https://doi.org/10.1111/j.1365-2028.2004.00467.x

[25] Iqbal, P.J., Pandit, A.K. and Javeed, J.A. (2006) Impact of Sewage Waste from Settlements on Physico-Chemical Characteristics of Dal Lake, Kashmir. *Journal of Research and Development*, **6**, 81-85.

[26] Silvaster, S. and Teresa, M. (2017) Evaluation of Metal Contamination in Water Samples by Inductively Coupled Plasma Atomic Emission Spectroscopy. *Research Journal of Environmental Sciences*, **11**, 130-136. https://doi.org/10.3923/rjes.2017.130.136

[27] Premlata, V. (2009) Multivariant Analysis of Drinking Water Quality Parameters of Lake Pichhola in Udaipur, India. *Biological Forum—An International Journal*, **1**, 97-102.

[28] Raburu, P.O. and Okeyo-Owuor, J.B. (2002) Impact of Agro-Industrial Activities on the Water Quality of River Nyando, Lake Victoria Basin, Kenya. Department of Fisheries and Aquatic Sciences, Moi University, Eldoret.

[29] Hlordzi, V., Kuebutornye, F.K., Afriyie, G., Abarike, E.D., Lu, Y., Chi, S. and Anokyewaa, M.A. (2020) The Use of Bacillus Species in Maintenance of Water Quality in Aquaculture: A Review. *Aquaculture Reports*, **18**, Article ID: 100503. https://doi.org/10.1016/j.aqrep.2020.100503

[30] Amoako, J., Ansa-Asare, O.D., Karikari, A.Y. and Dartey, G. (2011) Levels of Polycyclic Aromatic Hydrocarbons (PAHs) in the Densu River Basin of Ghana. *Environmental Monitoring and Assessment*, **174**, 471-480. https://doi.org/10.1007/s10661-010-1471-y

[31] Blackwell, M., Hogan, D. and Malty, E. (2012) Agriculture, Hydrology and Water Quality. CAB International, London.

[32] Cunningham, W.P., Cunningham, M.A. and Saigo, B.W. (2003) Environmental Science: A Global Concern. 7th Edition, McGraw-Hill Companies, New York, USA, 303-306.

[33] Akoto, O., Bruce, T. and Darko, G. (2008) Heavy Metals Pollution Profiles in Streams Serving the Owabi Reservoir. *African Journal of Environmental Science and Technology*, **11**, 354-359.

[34] Du, S., *et al.* (2021) Study on the Relationship between Suspended Solids Concentration and Turbidity in Coal Mine Water.

[35] Adenkunle, A.S. (2008) Impacts of Industrial Effluent on Quality of Well Water within Asa Dam Industrial Estate, Ilorin, Nigeria, *Nature and Science*, **7**, 39-43.

[36] Sekomo, C.B. (2012) Development of a Low-Cost Alternative for Metal Removal from Textile Wastewater. PhD Thesis, UNESCO-IHE Institute for Water Education, Delft.

[37] Waziri, M. and Ogugbuaja, V.O. (2010) Interrelationships between Physicochemical Water Pollution Indicators: A Case Study of River Yobe-Nigeria. *American Journal of Scientific and Industrial Research*, **1**, 76-80.

[38] Aniyikaiye, T.E., Oluseyi, T., Odiyo, J.O. and Edokpayi, J.N. (2019) Physico-Chemical Analysis of Wastewater Discharge from Selected Paint Industries in Lagos, Nigeria. *International Journal of Environmental Research and Public Health*, **16**, Article No. 1235. https://doi.org/10.3390/ijerph16071235

[39] Geofrey, W.W. (2020) Evaluation of the Effectiveness of a Wastewater Treatment Plant at the Export Processing Zone in Reducing Concentrations of Pollutants Discharged into River Athi, Kenya. Thesis, Pwani University, Kilifi.

[40] Jessica, B. (2013) Development of a Field Test for Total Suspended Solid Analysis. Theses Dissertation, Department of Civil Engineering, University of Nebraska-Lincoln, Lincoln.

[41] Safari, D., Mulongo, G., Byarugaba, D. and Tumwesigye, W. (2012) Impact of Human Activities on the Quality of Water in Nyaruzinga Wetland of Bushenyi District, Uganda. *International Research Journal of Environmental Sciences*, **1**, 1-6.

[42] Chapman, P.J., Kay, P., Mitchell, G. and Pitts, C.S. (2019) Surface Water Quality. In: Holden, J., Ed., *Water Resources*, Routledge, London, 99-150. https://doi.org/10.4324/9780429448270-4

[43] Moshood, K.M. (2008) Assessment of the Water Quality of Oyun Reservoir, Offa, Nigeria, Using Selected Physicochemical Parameters. *Turkish Journal of Fisheries and Aquatic Sciences*, **8**, 309-319.

[44] Gitari, W.M., Tshikovi, F.P. and Akinyemi, S.A. (2017) Physicochemical Appraisal of Effluents Receiving Streams: A Case Study of Mvudi River, South Africa. *Journal of Environmental Science and Allied Research*, **2017**, 25-31.

[45] Mwangi, J.K., Thiong'o, G.T. and Gathenya, J.M. (2012) Assessment of the Water Quality Status of Sasumua Watershed, Kenya.

[46] Hanson, R., Twumasi, A.K. and Boi-Doku, A. (2019) Analysis of Industrial Effluent from Some Factories in Tema. *European Journal of Earth and Environment*, **6**, 19-29.

[47] Jiang, G., Lutgen, A., Mattern, K., Sienkiewicz, N., Kan, J. and Inamdar, S. (2020) Streambank Legacy Sediment Contributions to Suspended Sediment-Bound Nutrient Yields from a Mid-Atlantic, Piedmont Watershed. *JAWRA Journal of the*

American Water Resources Association, **56**, 820-841. https://doi.org/10.1111/1752-1688.12855

[48] Wang, L., O'Connor, D., Rinklebe, J., Ok, Y.S., Tsang, D.C., Shen, Z. and Hou, D. (2020) Biochar Aging: Mechanisms, Physicochemical Changes, Assessment, and Implications for Field Applications. *Environmental Science & Technology*, **54**, 14797-14814. https://doi.org/10.1021/acs.est.0c04033

[49] Chance, L.M.G., Van Brunt, S.C., Majsztrik, J.C. and White, S.A. (2019) Short- and Long-Term Dynamics of Nutrient Removal in Floating Treatment Wetlands. *Water Research*, **159**, 153-163. https://doi.org/10.1016/j.watres.2019.05.012

[50] Tanner, C. and Sukias, J. (2011) Multiyear Nutrient Removal Performance of Three Constructed Wetlands Intercepting Tile Drain Flows from Grazed Pastures. *Journal of Environmental Quality*, **40**, 620-633. https://doi.org/10.2134/jeq2009.0470

[51] Kadlec, R.H. (2012) Constructed Marshes for Nitrate Removal. *Critical Reviews in Environmental Science and Technology*, **42**, 934-1005. https://doi.org/10.1080/10643389.2010.534711

[52] Cao, X., Zhou, X., Xue, M., Chen, J. and Li, S. (2021) Evaluation of Nitrogen Removal and N_2O Emission in a Novel Anammox Coupled with Sulfite-Driven Autotrophic Denitrification System: Influence of pH. *Journal of Cleaner Production*, **321**, Article ID: 128984. https://doi.org/10.1016/j.jclepro.2021.128984

[53] Xu, J.H., He, S.B., Wu, S.Q., Huang, J.C., Zhou, W.L. and Chen, X.C. (2016) Effects of HRT and Water Temperature on Nitrogen Removal in Autotrophic Gravel Filter. *Chemosphere*, **147**, 203-209. https://doi.org/10.1016/j.chemosphere.2015.12.136

[54] Ofori, I., Larbi, J.A., Abubakari, A., Addo, M.G. and Essiaw-Quayson, G. (2019) Microbial and Chemical Risk Assessment of River Bukuruwa Used as Drinking Water by Farming Communities. *International Journal of Biology*, **11**, 22-28. https://doi.org/10.5539/ijb.v11n1p22

[55] Huang, J., Jones, A., Waite, T.D., Chen, Y., Huang, X., Rosso, K.M. and Zhang, H. (2021) Fe(II) Redox Chemistry in the Environment. *Chemical Reviews*, **121**, 8161-8233. https://doi.org/10.1021/acs.chemrev.0c01286

[56] Sanjuan-Delmás, D., Josa, A., Muñoz, P., Gassó, S., Rieradevall, J. and Gabarrell, X. (2020) Applying Nutrient Dynamics to Adjust the Nutrient-Water Balance in Hydroponic Crops. A Case Study with Open Hydroponic Tomato Crops from Barcelona. *Scientia Horticulturae*, **261**, Article ID: 108908. https://doi.org/10.1016/j.scienta.2019.108908

[57] Tesha, M., Christiaan, C.D.P. and Johannes, H.B. (2021) Agricultural Phosphorus Management for Environmental Protection: A Review. *Journal of Geoscience and Environment Protection*, **9**, 48-81.