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The Role of Mara River Basin Wetland in Reduction of Nitrogen Load to Lake Victoria

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The role of Mara River basin wetland in reduction of nitrogen load to Lake Victoria was investigated. Reconnaissance survey was carried out to identify the suitable sampling points in the wetland. Transects were developed in the inlet and outlet zones of the wetland through which three sampling points were established at each transect. Data for physical-chemical parameters such as pH, temperature and dissolved oxygen were determined *in situ* and nitrite-nitrogen, nitrate-nitrogen, ammonia-nitrogen and total Kjedahl nitrogen were determined in the laboratory at Mwanza. Sediment samples were collected from the field by using soil auger and samples were taken to the laboratory for examination of nitrogen content in the sediments. The determination of nitrogen mass in plants involved determination of plant dominance, plant density and plant biomass before samples were taken to determine nitrogen in biomass. The results indicate that Mara River wetland receives about 0.70 ~ 1.56 mg/L of nitrogen largely in the form of organic nitrogen (63.6%) and nitrates (29.1%). The wetland removes about 28.8% of this nitrogen largely through net-loss to sediments and uptake by wetland plants. It is estimated that about 75 tons of nitrogen is removed annually, which is equivalent to 3.67 kg/ha/year. About 0.38 gN/kg of dry sediments were trapped in the benthic layer and 67.9 gN/m^2 of wetland is trapped in plant biomass. It was concluded that Mara River wetland was effectively protecting Lake Victoria by reducing nitrogen load entering the lake.

Key words: Lake Victoria, Mara River wetland, nitrogen removal, nitrogen load.

INTRODUCTION

Lake Victoria, the largest fresh-water Lake in Africa and the second largest in the world, is a resource of great social-economic potential in East Africa (UNEP, 2006). Its basin, which is estimated to accommodate over 40 million people, has numerous economic opportunities including fishing, tourism, water, energy, agriculture, trade and industry. More than 80% of the population living in the basin engages in small scale agriculture and animal husbandry (Makalle et al., 2008). Unfortunately, basin community agricultural practices, livestock overgrazing has led to serious land degradation and deforestation (Raburu and Okeyo-Owuor, 2005; Makalle et al., 2008; Twesigye et al., 2011; Thenya et al., 2005; Bancy et al., 2005). Similar problems were reported in other lakes in the region including Lake Kivu (Bagalwa, 2005), Lake Naivasha (Gichuki et al., 2005; Mironga, 2005; Amondi et al., 2005) and Lake Nakuru (Gichuki et al., 2005; Raini, 2005). Deforestation and land degradation causes soil erosion, which is the major cause of deterioration of water quality of natural water bodies such as rivers and lakes (Amondi et al., 2005). Soil erosion is largely caused by run-off, which pick up and transport sediments and pollutants resulting from agricultural, industrial, mining or any other economic activity. Agriculture is known to cause non-point source pollution, which is diffuse in nature and has complicated spatial and temporal dimension (Andrew, 1990; Henry and Semili, 2005; Amondi et al., 2005).

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As precipitation falls, run-off is created, which pick appreciable quantity of dissolved and adsorbed material that are carried away through hydraulic force of its flow (Kirkby and Morgan, 1980). Some of the adsorbed and dissolved substances found in run-off include nutrients from commercial fertilizers and animal manure (Rode and Lindenschmidt, 2000). Nutrients, sediments along with other pollutants such as heavy metals have contributed to ecological degradation of coastal marines and lakes including Lake Victoria (Henry and Semili, 2005; Omondi and Kusewa, 2005; Gichuki et al., 2005; Ongore et al., 2013). Globally, wetlands are known for their filtration capacity (Terer et al., 2005; Kansiime, 2004), maintenance of biodiversity (Hammer and Bastian, 1989; Muraza, 2013), retention of heavy metals (Marwa, 2013; Henry and Semili, 2005) and play a vital role as breeding ground for fish (Balirwa, 1995). Other benefits of wetlands include conserving wildlife, provision of products (such as fish, reeds, timber, firewood and medicines), microclimate stabilization, flood control and ground water recharge (CEC, 1995; Dugan, 1990; Maltby, 1990; Hogan et al., 1992). Wetlands are often cited as being effective at reducing nutrients loadings, acting as “the kidneys of the catchment” (Mitchell, 1994; Mitch and Gosselink, 1986) thereby reducing eutrophication in downstream water bodies. This has led to wetlands being managed or constructed as buffers or for treatment of domestic or industrial wastes (Allinson et al., 2000; Mayo and Bigambo, 2005; Marwa, 2013). The wetland vast buffering capacities and functions have attracted researchers’ interest around Lake Victoria in Uganda (Kansiime et al., 1994; Kansiime and van Bruggen, 2001), Kenya (Terer et al., 2005) and Tanzania (Henry and Semili, 2005; Muraza, 2013).

The Mara River Basin faces serious environmental and water resources problems, primarily from the intensive settlement and cultivation in the Mara River Basin leading to loss of vegetation cover, widespread soil erosion, decreased water infiltration capacity, decreased soil fertility and increased sedimentation as well as water pollution in the river (WWF, 2006; Nile Basin Initiative, 2007; Bitala et al., 2009). The Mara River basin wetlands have been receiving pollutants from large and small scale gold mines, agricultural activities and animal husbandry (Henry and Semili, 2005; Muraza, 2013; Marwa, 2013). Furthermore, the Mara River is a home to the wild animals of the Serengeti National Park in Tanzania and Maasai-Mara Game Reserve in Kenya. The Serengeti-Maasai-Mara is a World’s Heritage site and a Biosphere Reserve of global conservation significance and of great economic importance to the local communities. These economic and social activities adversely pollute the River. As a result, information on water quality of the river is needed for the planning of its management and the control of eutrophication in the river and Lake Victoria in general (WWF, 2006; Nile Basin Initiative, 2007). Such information is necessary for the efficient planning of long-term sustainable use of the Mara River basin wetlands (Nile Basin Initiative, 2007; Bitala et al., 2009).

This research was therefore carried out in order to determine the variation of water quality parameters in the Mara River basin wetland in order to address some of the unanswered questions.

MATERIALS AND METHODS

Study area

Mara River is an international river shared between Kenya and Tanzania. Its basin is about 13,750 km^2 of which about 65% is located in Kenya and 35% in Tanzania. The river originates from the forested Mau escarpment along the western rim of the Eastern Great Rift Valley in Kenya (at an altitude of 2,900 m above mean sea level), meanders through large scale agricultural farms, enters the Maasai-Mara and Serengeti National Parks in Kenya and Tanzania, respectively and ends its 395 km journey in Lake Victoria through Mara wetland (Figure 1). Annual rainfall on the Mara headwater watersheds ranges from 1400 to 1800 mm, while the lower regions receive only about 500 to 800 mm. The main hydrological processes in Mara wetland are mainly run-offs from Mara River inflows from upstream catchment that brings water into the wetland. From the wetland, water flows into Lake Victoria contributing to 37.5 m^3/s, which is about 4.8% of total discharge into Lake Victoria (LVEMP, 2005).

Mara wetland covers a total area of 204.46 km^2; its length is 36.8 km with a maximum width of 12.9 km (GLOWS, 2007). The wetland is situated between longitudes 34°00’ and 34°25’ East and between latitudes 1°08’ and 1°39’ South. At downstream part of the wetland at Kirumi Bridge, the wetland is about 6 km upstream of Lake Victoria. Administratively, the wetland lies between Tarime and Musoma rural districts of Mara region (GLOWS, 2007).

Sampling design

To establish the sampling points, the study site was surveyed to identify the suitable sampling points in the wetland (Figure 1). Some vegetation was to be cleared at some areas so as to provide accessibility and support during the sampling exercise. Sampling preparations also involved *in situ* identification of vegetation species located in various places so as to come up with the vegetation zonations. After the reconnaissance survey was done, transects were developed in the inlet and outlet zones in the wetland. Transect PT-1, which was largely covered by floating *Papyrus* mats, was located at the upstream end near Bisarwi village. Transect PT-2 was located downstream near Kirumi bridge at about 100 m upstream of the bridge and is dominated by mixed floating *Papyrus* and the rooted *Typha domingensis*. Through these transects, three sampling points were established at each transect. For each sampling location, a Global Positioning System (GPS) was used to record the sites’ coordinates; hence, helped in finding the site whenever sampling was done. Water, plants and sediments samples were taken since they are required for the modeling processes having some state variables of water, plants and sediments.

Collection of water samples and laboratory analysis

Forty-five (45) sets of water samples were collected during the whole study period between April and July 2012. Collection of water samples was done through inserting a 1 L plastic container up to

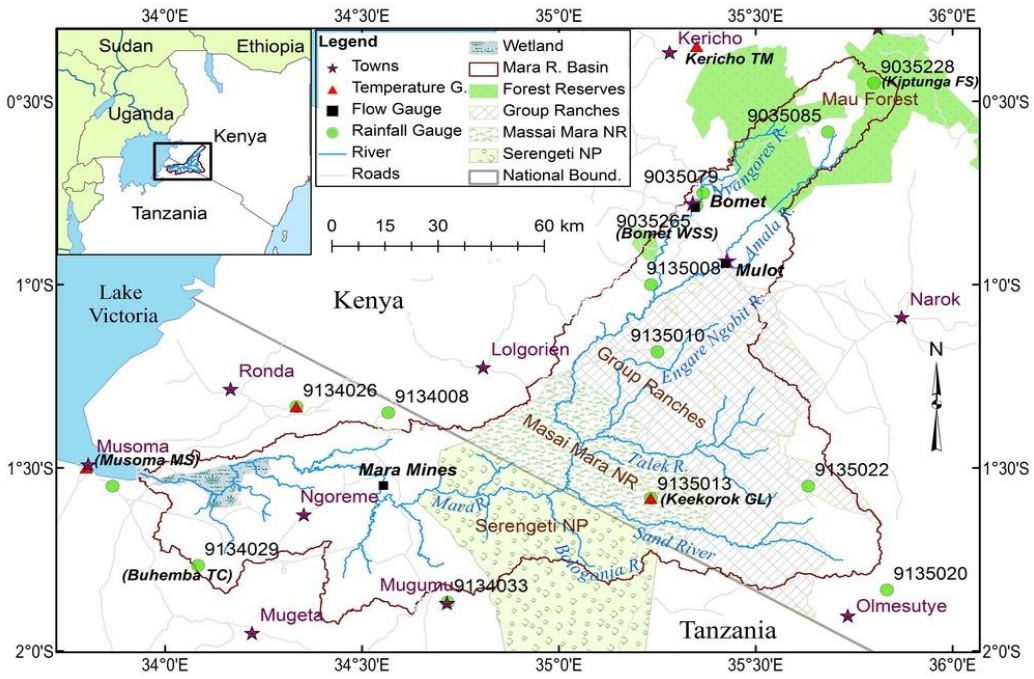

Figure 1. The location and relief of the Mara River Basin in Kenya and Tanzania.

the depth of about 30 cm deep and after the containers are filled with water, they were removed from the water column and kept in the cool box ready for transportation to the laboratory for analysis. Since prompt analysis of the samples was impossible, samples for analysis of ammonia nitrogen, total nitrogen and total Kjeldahl nitrogen were preserved with 0.8 ml conc. H_2SO_4 per litre of sample (to obtain a pH of 1.5 to 2.0), but those for analysis of nitrite nitrogen and nitrate nitrogen were not treated with an acid, they were stored at 4°C (together with those for analysis of ammonia nitrogen, total nitrogen and total Kjeldahl nitrogen after being treated with the acid) for one day in the Musoma Water laboratory before being transported to Mwanza water laboratory for analysis.

Water quality analysis

Parameters determined were physical parameters [pH, dissolved oxygen (DO) and temperature] and nutrients [nitrate nitrogen (NO_3^--N), nitrite nitrogen (NO_2^--N), ammonia nitrogen (NH_3-N), total nitrogen (TN) and total Kjedahl nitrogen (TKN)]. Temperature and pH were measured *in situ*. The pH was measured by a calibrated pH meter of Testo GmbH & Co. D-79849. Temperature was measured using temperature-meter Model HATCH HQ 30d. To obtain these parameters, probes were inserted into the water column (up to a depth of about 30 cm) and readings were taken after stabilization of the probes. Dissolved oxygen concentrations were analyzed in the Musoma Water Laboratory by Winkler titration method this is due to the fact that the DO-meter's probe did not stabilize even after a very long calibration; hence, we had to opt for the laboratory analysis. Water samples for dissolved oxygen determination were taken using special dissolved oxygen sampling bottles and preservation before analysis was done in accordance with Standard Methods (2012). Nutrients (NO_3^--N, NH_3-N, NO_2^--N, TN and TKN) analysis for water samples was carried out following procedures outlined in the standard methods for examination of water and wastewater (Standard Methods, 2012) at the Mwanza Water Laboratory. Both NO_3-N and NH_3-N were analyzed using Spectrophotometer with Cadmium Reduction and Turbidmetric methods respectively.

Nitra Ver.5 and Nessler reagents were used for NO_3^--N and NH_3-N analysis respectively. NO_2^--N was analyzed using calorimetric method with a spectrophotometry machine, UV-2001, TN was analyzed using the per sulphate digestion method and TKN was analyzed using the Semi-Micro Kjeldahl method.

Sediment sampling and analysis for nitrogen content determination

Sediments samples were collected eight times during the study period with the use of a soil auger. The obtained samples from the three points within each transect were packed in a cool box and transported to the laboratory in Mwanza. In the laboratory, samples were oven dried at 105°C. After drying, the samples were ground in a mortar and pestle, sieved through a 0.5 mm sieve size to obtain the dry powder. To analyze sediments for nitrogen contents, sub-samples with appropriate weights were taken and digested in a block using a concentrated sulphuric-salicylic mixture with selenium as a catalyst. Then, the analysis for nitrogen contents was done according to Standard Methods (2012).

Data and statistical analyses

Data analysis involved organizing the water quality data into the following data sets; the entire set of the two (inflow and outflow) systems, the inflow data separated into its three sampling points and the outflow separated into its three sampling points. For these data sets, the inflow and outflow data were kept separate to perform additional analysis for example to calculate the daily average values. Analysis of the data included statistical correlations and statistical differences between the data. The water quality,

Table 1. Characteristics of observed influent and effluent parameters.

Parameter	Influent value		Effluent value	
	Range	Mean	Range	Mean
pH	6.71- 7.27	6.95±0.16	6.34-7.17	6.85±0.29
Temperature (ºC)	21.3-24.1	22.5±0.83	22.0-24.6	23.25±0.87
Dissolved Oxygen (mg/l)	1.3 - 4.8	3.16±0.99	2.6-4.9	3.85±0.74

Where number of samples (n) for all the parameters = 44.

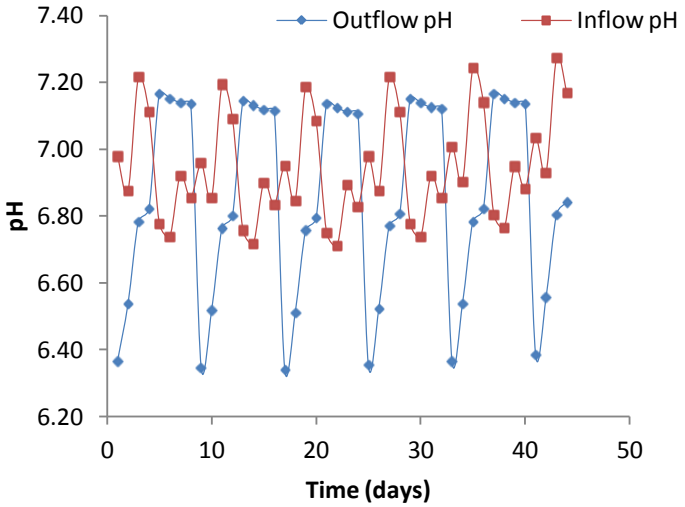

Figure 2. Variation of inflow and outflow pH with time**.**

sediments nutrients contents and plant nutrients contents data received from the laboratory were analyzed to check for their correctness. Constituents measured during the study were analyzed using Easy Fit 5.5 and Excel software systems, respectively. Spearman correlation tests were performed on various data sets to examine relationships between constituents. Correlation analyses measure the linear relationships between constituents and were performed using Spearman's rank-order linear relationships by looking at the coefficient, which ranges from -1.0 to +1.0. The stronger the relationship between constituents the higher the coefficient (±1 = a perfect correlation).

RESULTS

Variation of physical-chemical parameters

Table 1 shows that the pH of the water in the wetland ranged from 6.71 to 7.27 with a mean value of 6.95 ± 0.16 at the inlet zone while at the outlet zone it ranged from 6.34 to 7.17 with a mean value of 6.85 ± 0.29 at 95% confidence interval (α = 0.05). Figure 2 shows the variation of inflow and outflow pH in the wetland with time. The observed outflow pH value suggests that microbial activities in the wetland are favored since this pH is within their normal functioning pH range (Kadlec, 2009). The dissolved oxygen concentration ranged from 1.3 to 4.8 mg/L with a mean value of 3.16 ± 0.99 mg/L at the inlet zone whereas at the outlet zone it ranged from 2.6 to 4.9 mg/L with a mean value of 3.85 ± 0.74 mg/L at the 95% confidence interval (Table 1). Dissolved oxygen values suggest that the wetland is fairly aerated. Dissolved oxygen increased by 21.8% in the wetland suggesting that the water was significantly oxygenated by the biochemical activities taking place in the wetland, particularly the photosynthesis of the vegetations which gives out oxygen (Figure 3). Water temperature ranged from 21.3 to 24.1°C with a mean value of 22.5 ± 0.83°C at the inlet and 22.0 to 24.6°C with a mean value of 23.25 ± 0.87°C at the outlet zone (Table 1 and Figure 4). The pH had a very strong relationship with temperature (R = 0.937) as shown by Figure 5, suggesting that the variations of temperature in the wetland have a direct effect on the pH. This is because under limiting conditions, temperature which is influencing photosynthetic consumption of CO_2 causes bicarbonate to dissociate and release hydroxyl ions.

On the other hand, Kayombo et al. (2000, 2002) observed that dissolved oxygen, which is largely generated by photosynthesis, is a function of temperature and light intensity. The temperature and light intensity's influence on photosynthetic activities limit the maximum algal growth thus limits the maximum substrate utilization. Conversely, good correlation between dissolved oxygen with temperature (R = 0.773) indicates that temperature is one of the limiting factors for photosynthesis (Figure 5).

Ammonia nitrogen

Figure 6 shows the variation of inflow and outflow ammonia nitrogen concentrations with time. The concentration of ammonia nitrogen ranges from 0.005 to 0.632 mg/L with a mean value of 0.063 ± 0.017 mg/L and from 0.005 to 0.128 mg/L with mean value of 0.028 ± 0.023 mg/L for inflow and outflow zones, respectively (Table 2). The observed mean values gave an ammonia nitrogen removal efficiency of 55.6%, which was probably caused by nitrification of ammonia as a result of adequate dissolved oxygen favourable temperature and near optimum pH values. The evidence of strong correlation (R = 0.835) between the inflow and outflow concentration of ammonia is shown in Figure 7(a).

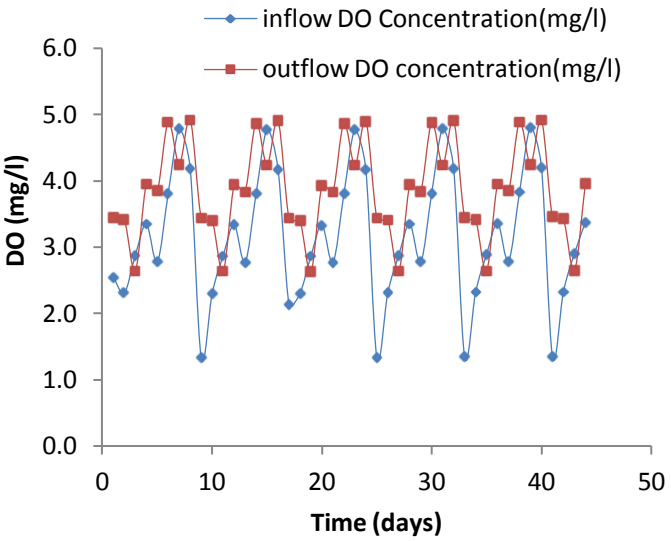

Figure 3. Variation of inflow and outflow DO concentrations with time

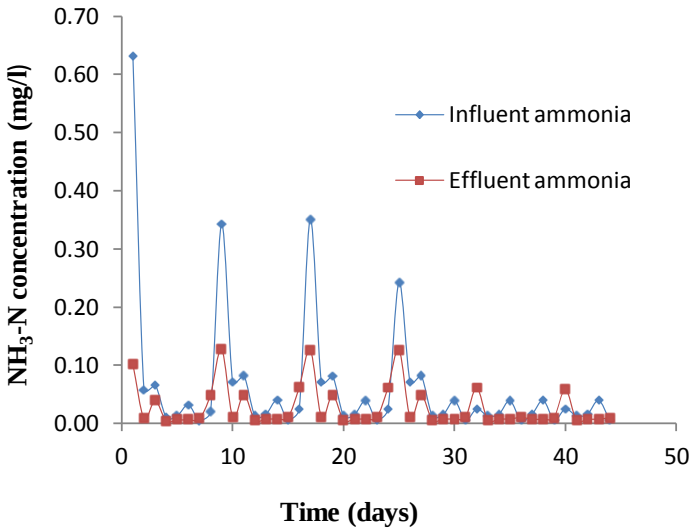

Figure 6. Variation of inflow and outflow NH_3-N concentrations with time.

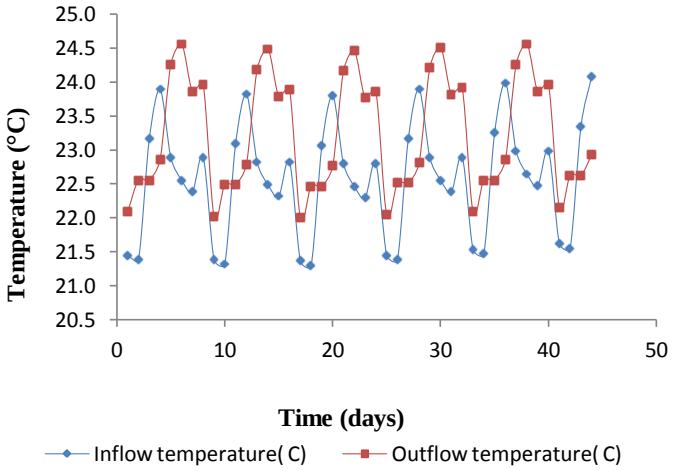

Figure 4. Variation of inflow and outflow temperature with time

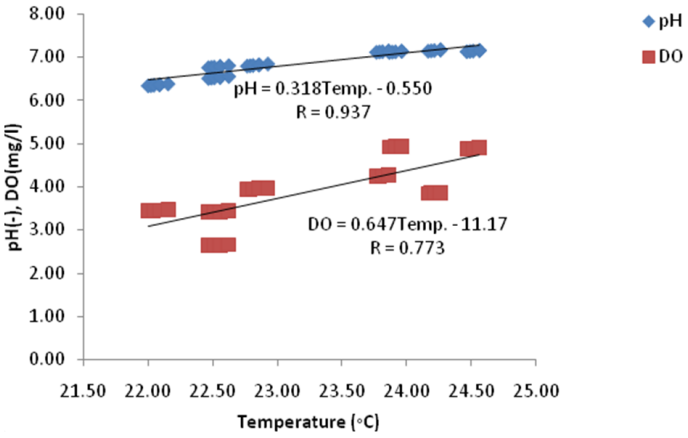

Figure 5. Variation of effluent pH and DO with temperature.

Nitrite- and nitrate-nitrogen

Table 2 shows that concentration of nitrite nitrogen ranged from 0.002 to 0.062 mg/L with a mean value of 0.01 ± 0.007 mg/L and from 0.002 to 0.026 mg/L with a mean value of 0.009 ± 0.006 mg/L for inflow and outflow zones, respectively. Nitrite is usually obtained from biological oxidation of oxidation of ammonia, which is later followed by its oxidation to nitrates. The concentration of nitrites is generally low (Table 2) in oxygen-rich waters (Table 1) because degradation of ammonia to nitrite is usually the rate limiting step of nitrification. Figure 8 shows the variation of inflow and outflow nitrate nitrogen concentrations with time. The average concentration of nitrate-nitrogen ranged from 0.062 to 0.39 mg/L with a mean value of 0.284 ± 0.08 mg/L and from 0.132 to 0.507 mg/L with a mean value of 0.310 ± 0.133 mg/L for inflow and outflow zones, respectively (Table 2). As a result of nitrification, mean nitrate concentration increased by about 9.2% as water flows through the wetland. The Spearman's correlation tests between outflow nitrate nitrogen with dissolved oxygen, temperature and pH gave correlation coefficients of 0.469, 0.723 and 0.711, respectively. This is suggesting that the outflow nitrate nitrogen concentrations are strongly correlated with dissolved oxygen, temperature and pH. It was noted that temperature and pH depicted strong correlation with effluent nitrate concentration (Figure 9). However, correlation between oxygen and effluent concentration of nitrate was relatively poor, although it was generally observed that concentration of nitrate in the effluent was stimulated by increase in dissolve oxygen (relationship: NO_3-N = 0.076 DO with R = 0.469; DO and Nitrate in

Table 2. Variation of nitrogen in wetland system.

Parameter	Influent value		Effluent value	
	Range	Mean	Range	Mean
Nitrate nitrogen (mg/l)	0.062-0.39	0.28±40.08	0.132-0.507	0.310±0.133
Nitrite nitrogen (mg/l)	0.002-0.062	0.010±0.007	0.002- 0.026	0.009±0.006
Ammonia nitrogen (mg/l)	0.005-0.632	0.063±0.017	0.005-0.128	0.028±0.023
Organic nitrogen (mg/l)	0.181-2.29	0.621±0.535	0.08-0.746	0.349±0.152
TN (mg/l)	0.699-1.563	0.977±0.243	0.457-1.015	0.695±0.178
TKN (mg/l)	0.195-2.63	0.684±0.625	0.153-0.715	0.377±0.168

Where number of samples (n) for all the parameters = 44.

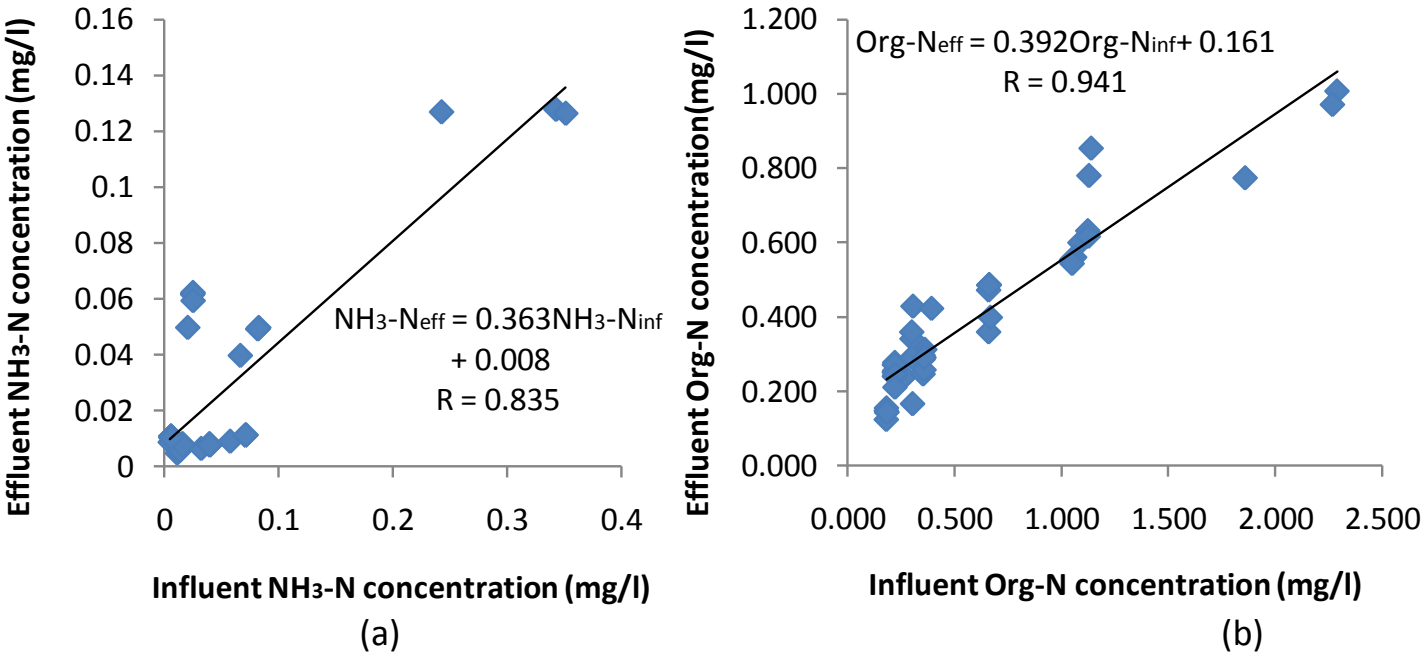

Figure 7. Variation of (a) Influent NH_3-N and Effluent NH_3-N and (b) Influent Organic Nitrogen and Effluent Organic Nitrogen.

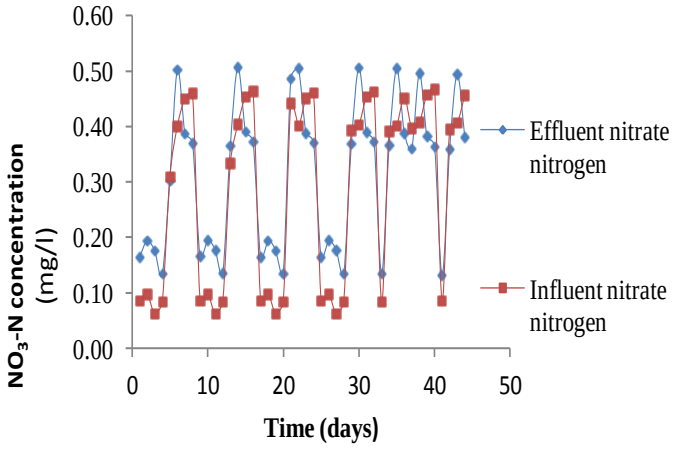

Figure 8. Variations of inflow and outflow NO_3-N concentrations with time.

mg/l).

Nitrification is affected by pH, temperature, dissolved oxygen and substrate concentrations. At dissolved oxygen values of less than 2 mg/L, nitrification is hindered while the optimum temperature for nitrification to take place is 20 to 30°C and pH optimum for this is 7.2 to 8.5, though nitrification under some conditions can proceed even below pH of 7.2 (Seitzinger, 1988). The observed values of pH, temperature and dissolved oxygen are at more or less optimal conditions for nitrification. On the other hand, denitrification in many wetland ecosystems is largely regulated by nitrification rates (Reddy et al., 1989; Vymazal, 2007). When the river water is not only nitrate-rich, but also oxygen-rich, denitrification will only occur if oxygen concentrations will drop to sufficiently low levels (Seitzinger, 1988). The aforementioned observations and discussions suggests

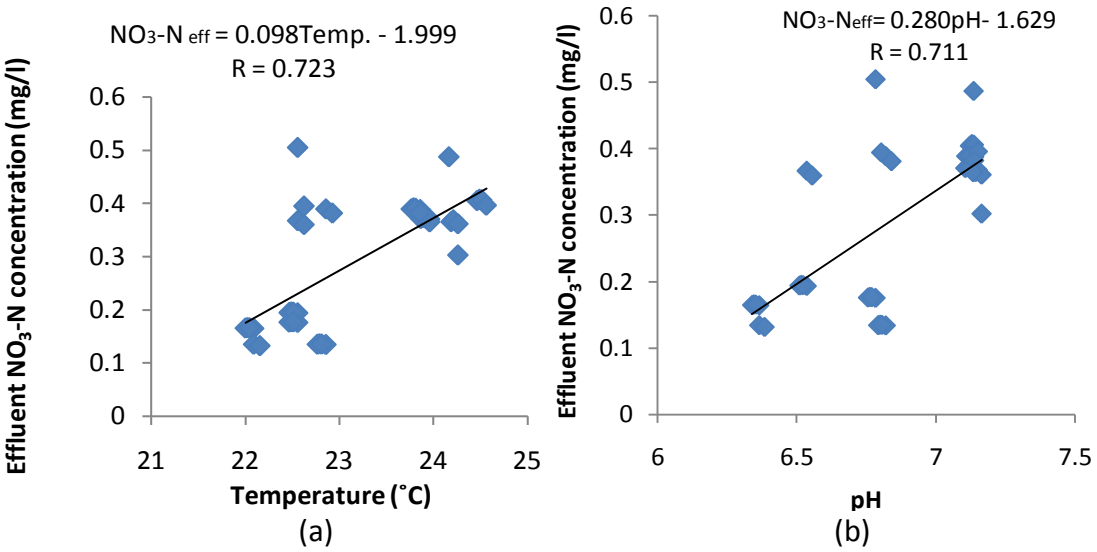

Figure 9. Graph of effluent NO_3-N concentration vs (a) Temperature and (b) pH.

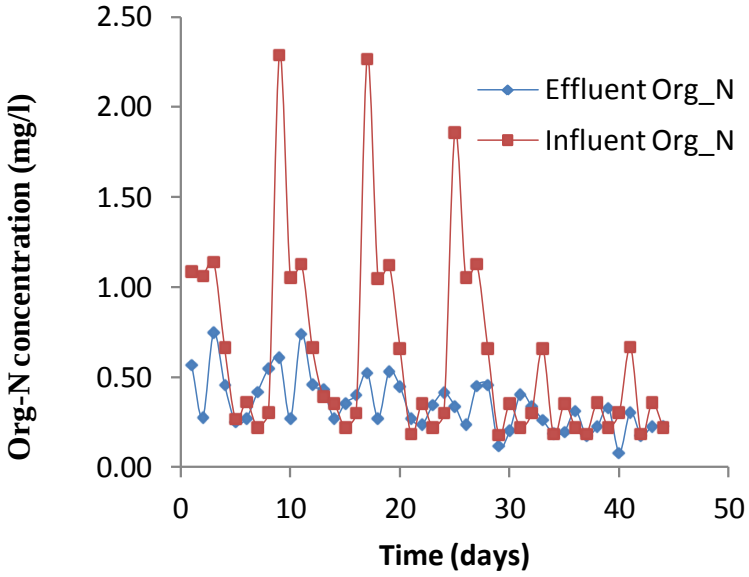

Figure 10. Variation of inflow and outflow Org-N concentrations with time.

that the nitrate nitrogen formation in the wetland is being favored considering the optimal levels of dissolved oxygen, pH and temperature, and the decreasing trend of ammonia nitrogen from which nitrate nitrogen emanates.

Organic nitrogen

Concentrations of organic nitrogen ranged from 0.181 to 2.29 mg/L with a mean value of 0.621 ± 0.535 mg/L and from 0.08 to 0.746 mg/L with a mean value of 0.349 ± 0.152 mg/L for inflow and outflow zones, respectively (Figure 10). The observed organic nitrogen removal efficiency is 43.8%, which is substantial and can be regarded as one of the major transformation processes observed in the wetland. It is worth noting that effluent concentration of organic nitrogen was strongly correlated (R = 0.941) to the influent concentration of organic nitrogen (Figure 7b).

Total nitrogen (TN)

Total nitrogen concentrations ranged from 0.699 to 1.563

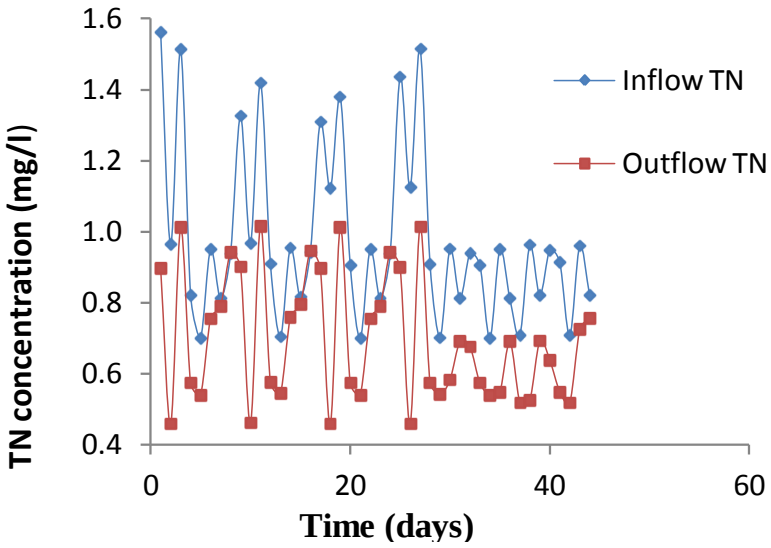

Figure 11. Variation of inflow and outflow TN with time.

mg/L with a mean value of 0.977 ± 0.243 mg/L and from 0.457 to 1.015 mg/L with a mean value of 0.695 ± 0.178 mg/L for inflow and outflow zones, respectively (Table 2), which is equivalent to 28.8% removal efficiency (Figure 11).

Estimating nitrogen content for the wetland plants

Plants nitrogen content determination was estimated by the application of the plants biomass (DWm^{-2}) and nitrogen content (%DW) data respectively, as detailed under the methodology part. After the plants biomass content (in $kgDWm^{-2}$) and the plants nitrogen content (in %DW) were determined, the final plants nitrogen content was determined (in gm^{-2}) as a product of biomass and nitrogen content. Mean plants nitrogen content found was 67.88 gNm^{-2}; this was used as a model input for the plants nitrogen. Table 3 shows the detailed nitrogen content determination process.

Nitrogen content in sediments

The results of the sediments' nitrogen content from the three transects shows that transect close to inlet of wetland has 0.22 ± 0.045 gN/kg, at the middle of wetland has 0.362 ± 0.063 gN/kg and near the exit has 0.577 ± 0.2 gN/kg of dry sediments. It is evident that more nitrogen accumulates in the sediments as water approaches the exit end of the wetland. This can be attributed by the increase in plants density whose roots and below ground formations in general helps in sediment trap; hence, nutrient retention in the sediments. The average nitrogen content of the wetland is about 0.38 ± 0.06 gN/kg of sediments, which translates to 201.26 ± 30.78 g/m^2 of wetland.

DISCUSSION

The concentration of total nitrogen in Mara River at Bisarwi village ranged from 0.70 to 1.56 mg/L, which was largely contributed by organic nitrogen (63.6%) and nitrates (29.1%). The concentration of organic nitrogen ranged from 0.18 to 2.29 mg/L, nitrates from 0.06 to 0.39 mg/L and ammonia from 0.005 to 0.63 mg/L. These values are lower than those reported by Kulekana (2004) who observed nitrate concentration of 0.91 mg/L near the water surface, which decreased to 0.35 mg/L at the bottom 0.5 m of River Mara. It is possible that dilution effect during April to July, which is just after rainy season in the area, reduced concentration to low levels in the river. Kulekana (2004) also reported dilution effect during rainy season reduced concentration of nutrients in Lake Malimbe, Burigi and Mara River. Mara River wetland removed total nitrogen by about 28.8% from an average of 0.98 mg/L at the inlet of wetland to 0.70 mg/L at the exit of wetland near Kirumi Bridge. This is substantial removal efficiency for a wetland that retained water for only 36 h. The removal was largely due to deposition of organic nitrogen in the wetland sediments. Organic nitrogen decreased from 0.62 mg/L at the inlet of the wetland to 0.35 mg/L at the exit. Some nitrification of ammonia was also observed as ammonia-nitrogen decreased from 0.063 to 0.028 mg/L in the wetland system, which resulted in a slight increase of nitrate from 0.28 to 0.31 mg/L.

The Spearman's correlation test between nitrate concentration at the exit of the wetland with temperature

Table 3. Plants nitrogen content.

Plant	Biomass (KgDWm^{-2})			Nitrogen content (%DW)			Nitrogen content (gm^{-2})		
	AG	BG	Total	AG	BG	Total	AG	BG	Total
Papyrus	2.52± 0.5	1.78± 0.39	4.3± 0..4	2.48± 0.2	0.87± 0.12	3.35± 0.22	62.49	15.49	77.98
Phragmites	2.3± 0.38	1.44± 0.19	3.74±0.23	2.72± 0.5	0.91± 0.2	3.63± 0.7	62.56	13.10	75.66
Typha	1.53± 0.25	1.17± 0.4	2.7± 0.55	2.61± 0.25	0.86± 0.1	3.47± 0.6	39.93	10.06	49.99
Average	**2.12± 0.52**	**1.46± 0.31**	**3.58±0.8**	**2.60± 0.12**	**0.88± 0.03**	**3.48± 0.14**	**55.00± 13**	**12.88± 2.71**	**67.88± 15.53**

AG= above ground organs; BG= below ground organs.

and dissolved oxygen gave correlation coefficients of 0.71 and 0.469, respectively. However, the concentrations of nitrate, ammonia and organic nitrogen in the influent were poorly correlated with temperature. This is suggesting that an increase in temperature, which is also strongly correlated with increase in dissolved oxygen (R = 0.773), resulted in increase of nitrate concentration. Having such a strong correlation and taking into account that temperature is one of the limiting factors for microbial activities in the nitrification/denitrification processes, it can be suggested that if other limiting factors like dissolved oxygen concentration are kept constant, temperature is at the optimal microbial functioning range as Vyamazal (2007) suggested that the activities of nitrifying and de-nitrifying bacteria in treatment wetlands proceed most efficiently at 20 to 25°C. Vandelannoote et al. (1996) reported higher nutrient levels in Ntahangwa River during the dry season compared to rainy season. Slight increase of nitrate levels may also be associated with the increased rate of deposition and mineralization of organic matter (Battle and Mihuc, 2000; Mayo and Mutamba, 2004) and subsequent increased nitrification as a result of high levels of dissolved oxygen in the wetland.

Muraza (2013) reported that flow rate in Mara River at Bisarwi village ranged from 5.8 to 14.2 m^3/s with a mean value of 8.5 ± 0.3 m^3/s, which is equivalent to 734,400 ± 229,279 m^3/d. Assuming the outflow rate of river near Kirumi Bridge is equal to the inflow rate, 75 tons of nitrogen is removed by the wetland annually, which is equivalent to 3.67 kg/ha/year. Nitrogen may be removed through nitrification, denitrification, uptake by wetland plant, settling of organic matter to sediments or ammonia volatilization (Bigambo and Mayo, 2005). The later mechanism is unlikely to occur in Mara River wetland because wetland water pH is near neutral (Table 1), whereas ammonia stripping is possible only when pH exceeds 9.4 (Reddy and Graetz, 1981). Samples from sediments indicated mean nitrogen levels of 0.38 ± 0.06 g/kg dry sediments, with wetland outlet zone sediments having 2.62 times more nitrogen than the inlet zone. This is in line with the observed organic nitrogen removal rate of 43.8%. It is worth mentioning that total nitrogen removal in the wetland was only 28.8%, which suggests that part of the organic matter deposited in the sediments was regenerated back to the water body and/or some organic matter was transformed to ammonia through mineralization. The analysis of plant nitrogen suggests that significant amount of nitrogen is contained in plant biomass (Table 4). Taking into consideration of plant biomass, the estimated nitrogen content is 678.8 kg/ha, which is assumed to be removed from the river water. Since the area of Mara River wetland is 204.46 km^2, the total nitrogen in wetland plants is about 13,879 tons. This is substantial amount of nitrogen that has been prevented from entering Lake Victoria waters.

From the findings of this study, it is suggested that for better functioning of the wetland, best management practices should be undertaken, since the wetland's functionality is a function of the biogeochemical relationships between the micro organisms, the geological features and plants complexes. For the wetlands to function as anticipated, the best management strategies should address the issues for making sure that this ecosystem's functioning is at its best level. To achieve this, strategies proposed for sustainable use while maintaining ecological and biodiversity quality include, but are not limited to, nutrient load reduction from the point and non point sources, creation and maintenance of buffer zones and wetland's participatory monitoring over its functionality (Muraza, 2013).

Conclusions

From the results of this research work, the following conclusions are made:

i) Mara River wetland receives about 0.70 ~ 1.56 mg/L of nitrogen, which is largely contributed by organic nitrogen (63.6%) and nitrates (29.1%). The wetland removes about 28.8% of the nitrogen it receives within 36 h of water retention in it.

ii) The wetland removes about 75 tons of nitrogen annually, which is equivalent to 3.67 kg/ha/year. It is estimated that about 0.38 g of nitrogen is trapped in each kg of dry sediments and about 67.9 g/m^2 is trapped in plant biomass. It can be concluded that Mara River wetland is effectively protecting Lake Victoria by reducing nitrogen load entering the lake.

Table 4. Nitrogen biomass in plants.

Plant	*Cyperus papyrus*	*Phragmites australis*	*Typha domingensis*
Rhizomes + roots (%DW)	0.87± 0.12	0.91± 0.08	0.86± 0.50
Culm (%DW)	1.09± 0.05	1.17± 0.10	1.13± 0.06
Umbel (%DW)	1.47± 0.03	1.55± 0.40	1.49± 0.18
Total (%DW)	3.35±0.22	3.63± 0.70	3.47± 0.45
Above ground (%DW)	2.37±0.22	2.42± 0.17	2.39± 0.20
Below ground (%DW)	1.03± 0.10	0.80± 0.40	0.90± 0.10

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