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Modelling nitrogen transformation and removal in mara river basin wetlands upstream of lake Victoria

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ABSTRACT

Lake Victoria, the largest lake in Africa, is a resource of social-economic potential in East Africa. This lake receives water from numerous tributaries including Mara River, which contributes about 4.8% of the total Lake water inflow. Unfortunately, Mara River basin faces environmental problems because of intensive settlement, agriculture, overgrazing in the basin and mining activities, which has lead to water pollution in the river, soil erosion and degradation, decreased soil fertility, loss of vegetation cover, decreased water infiltration capacity and increased sedimentation. One of the pollutants carried by the river includes nitrogen, which has contributed to ecological degradation of the Lake Victoria. Therefore this research work was intended to determine the effectiveness of Mara River wetland for removal of nitrogen and to establish nitrogen removal mechanisms in the wetland. To predict nitrogen removal in the wetland, the dynamics of nitrogen transformation was studied using a conceptual numerical model that takes into account of various processes in the system using STELLA II version 9.0® 2006 software. Samples of model input from water, plants and sediments were taken for 45 days and were analyzed for pH, temperature, and DO *in situ* and chemical parameters such as NH_3-N, Org-N, NO_2-N, and NO_3-N were analyzed in the laboratory in accordance with *Standard methods*. For plants, the density, dominance, biomass productivity and TN were determined and for sediments TN was analyzed. Inflow into the wetland was determined using stage-discharge relationship and was found to be 734,400 m^3/day and the average wetland volume was 1,113,500 m^3. Data collected by this study were used for model calibration of nitrogen transformation in this wetland while data from another wetland were used for model validation. It was found that about 37.8% of total nitrogen was removed by the wetland system largely through sedimentation (26.6%), plant uptake (6.6%) and denitrification (4.6%).

1. Introduction

Mara River with catchment area of about 13,750 km^2 is one of the major rivers discharging its water to Lake Victoria, which is the largest lake in Africa and the second largest lake in the world. In accordance with UNEP (2006), Lake Victoria is a resource of social-economic potential in East Africa as it accommodates about 40 million people, over 80% of whom are engaged in small scale agriculture and animal husbandry (Makalle et al., 2008). The Mara River and Lake Victoria basins provide numerous economic opportunities to its inhabitants including tourism, fishing, agriculture, trade, water supply, industry and energy. For example, Mara River meanders through Serengeti National Parks in Tanzania, the World's Heritage site and a Biosphere Reserve of global conservation significance and Maasai- Mara Wildlife Park in Kenya (Muraza, 2013).

Mara River's contribution to Lake Victoria amounts to about 4.8% of the total lake tributary inflow (LVEMP, 2005; WWF, 2006; Nile Basin Initiative, 2007; Bitala et al., 2009). Its basin sustains livelihood of 1.1 million people, 70% of this population live in Kenya and 30% in Tanzania. Musoma in Tanzania and Bomet in Kenya are the largest urban centers with population of about 121,100 and 83,700 residents, respectively. The rest of the population lives in rural areas and depend on small scale agriculture and animal husbandry, with up to 64% living below the poverty line (Muraza, 2013). Unfortunately, agricultural practices in Lake Victoria basin and livestock overgrazing has significantly contributed to land degradation and deforestation (Bancy et al., 2005; Raburu and Okeyo-Owuor, 2005; Twesigye et al., 2011).

Mara River basin faces water resources and environmental problems because of intensive settlement, mining, agriculture and overgrazing in the basin, which has leads to water pollution in the river, soil erosion and degradation, decreased soil fertility, loss of vegetation cover, decreased water infiltration capacity and increased sedimentation (WWF, 2006; Nile Basin Initiative, 2007; Bitala et al., 2009). Agriculture, which is practiced by more than 80% of the residents of Mara River

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basin, has been reported as the major non-point diffuse source pollution with complicated temporal and spatial dimensions (Amondi et al., 2005; Henry and Semili, 2005). Nutrients from animal manure and commercial fertilizers are absorbed and dissolved in run-off and transported to river network (Rode and Lindenschmidt, 2001). Nutrients, together with heavy metals from industrial and mining sectors have contributed to ecological degradation of the Lake Victoria environment (Henry and Semili, 2005; Ongore et al., 2013).

The wetland vast buffering functions and capacities have attracted various scholars' interest around Lake Victoria in Tanzania (Henry and Semili, 2005; Mayo et al., 2013; Muraza et al., 2013), Kenya (Terer et al., 2005) and Uganda (Kansiime et al., 1994; Kansiime and van Bruggen, 2001). They are known for their maintenance of biodiversity (Hammer and Bastian, 1990; Muraza, 2013), filtration capacity (Kansiime, 2004; Terer et al., 2005), 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 stabilization of microclimate, wildlife conservation, recharge of ground water, control of floods, and provision of products such as firewood, fish, reeds, medicines and timber (Dugan, 1990; Maltby, 1990; Hogan et al., 1992; CEC, 1995).

Mara River wetland receives pollutants from non-point wildlife reserves, agriculture and animal husbandry and large and small scale gold mines (Marwa, 2013; Muraza et al., 2013). In accordance with Muraza (2013), Mara River discharges up to 1200 kg/d of nitrogen into the wetland. Some researchers have indicated that this wetland have a potential to effectively reduce nitrogen loading into Lake Victoria, which will enhance reduction of its eutrophication (Mayo et al., 2013; CGIAR, 2016). Therefore understanding of the nitrogen dynamics of the river and effectiveness of its reduction in the wetland, will improve our knowledge on dynamics of nitrogen transformation in the wetland, which is necessary for proper planning of its management and protection of the Lake water quality.

To understand nitrogen removal mechanisms in the wetland, it was considered necessary to use numerical models for prediction of nitrogen recycling in the wetland environment. Biogeochemical transformation of nitrogen in wetlands is a complex process, which involves transfer among the storage compartments and inter-conversions between different forms of nitrogen (Huang and Pant, 2009). In addition, nitrogen may be stored in the plants, sorbed on organic and inorganic matter, consumed by the microbes, deposited into the sediments or released into the air (Bigambo and Mayo, 2005; Mayo and Bigambo, 2005; Huang and Pant, 2009). Transformation pathways include mineralization, nitrification, denitrification, plant and microbial assimilation, ammonia volatilization and regeneration from benthic layer. Dynamics of nitrogen recycling in a wetland is a complex process and requires a numerical model as a tool for its analysis in order to indentify the relative importance sinks of nitrogen in a wetland environment. Therefore the main objective of this work was to study the dynamics of nitrogen transformation and predict nitrogen removal capacity of the Mara River wetland, which may lead to the establishment of the best management strategies for Mara River basin wetlands for sustainable use while maintaining ecological and biodiversity quality.

2. Materials and methods

2.1. The study site

Mara wetland is estimated to cover an average area of about 164 km^2, which varies from about 186 km^2 in the rainy season to 135 km^2 in the dry season (CGIAR, 2016). However, GLOWS (2007) estimated that the wetland covers 204.46 km^2 with a length is 36.8 km and maximum width of 12.9 km. In accordance with Fig. 1 the wetland area is approximately 196.3 km^2 and has a maximum length of about 12.5 km. The wetland is situated at longitudes 34°00′ East and 34°25′ East and between latitudes 1°08′ South and 1°39' South. At downstream part of the wetland in Kirumi Bridge, the wetland is about 6 km north of Lake Victoria. Administratively, the wetland lies between Tarime and Butiama districts of Mara region (Mayo et al., 2013). The mean annual rainfall in the Mara River basin varies from 1000 to 1750 mm/year in Mau escarpment in Kenya; 900–1000 mm/year in the middle rangelands and a low rainfall amount of 700–800 mm/year on the downstream Mara wetland around Lake Victoria in Mara region. The warmest months of this area are October and February and the coolest month is July (LVEMP, 2005). 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, this is about 4.8% of total discharge into Lake Victoria (LVEMP, 2005).

2.2. Sampling design

Field surveys were done at various transversal positions in the wetland with different vegetation zonation in order to establish suitable sampling points in the wetland. Some vegetation was cleared in order to access the established sampling points. Vegetation zonations were established through *in situ* identification of vegetation species located in various places. Reconnaissance survey was followed by development of transects in the inlet and outlet zones of the wetland (see Fig. 1).

Water samples for examination of water quality parameters were collected at PT-1 near upstream end at Bisrawi village and at PT-2 near the downstream end at Kirumi Bridge. Four transects were established for investigation of biomass density, dominance and nitrogen content in the soil and plants. Transect T-1, 2.4 km long and 4.8 km downstream of PT-1, was located at the upstream end of the wetland near Bisarwi village, where the main vegetation is the floating papyrus mats. Transect T-4, which 3.2 km long and 6.8 km upstream of PT-2, was located downstream at about 100 m upstream of Kirumi bridge and is dominated by mixed floating *papyrus* and the rooted *typha*. Through these transects three sampling points were established at each transect. Three sub-sample replicates were collected at each sampling station. Two more transects were established one near the western end of the wide shallow flood plain with the length of 12 km (T-3) and the other near the Eastern edge of the wide part of flood plain with the length of 12.5 km (T-2). Transects T-2, T-3 and T-4 were 6.8 km, 6.8 km and 7.8 km downstream of transects T-1, T-2 and T-3, respectively. For each sampling location a global positioning system (GPS) was used to record the sites' coordinates, which helped in locating the site whenever sampling was done.

2.3. Examination of water samples

Forty five (45) sets of water samples for determination of physical-chemical parameters were collected between April and July 2012 at the interval of two to three days. This period was predominantly rainy season in the study area with maximum and minimum flow rates of 14.2 m^3/s and 5.8 m^3/s recorded in April and July, respectively. Water samples for examination of physical-chemical parameters were collected at a depth of about 30 cm from the surface by inserting a 1 L plastic container. All procedures for collection and storage of samples prior to analysis were followed (AWWA et al., 2012). Nitrate-nitrogen and ammonia-nitrogen were examined spectrophotometrically using Cadmium Reduction and Turbidimetric methods, respectively. Nitrite-nitrogen was analyzed using Calorimetric method, UV-2001, TN was analyzed using the per sulphate digestion method and TKN was analyzed using the Semi-Micro Kjeldahl method. All measurements were done in accordance with Standard methods (AWWA et al., 2012). Temperature and pH were measured *in situ* using thermometer Model HATCH HQ 30d and a calibrated pH meter of Testo GmbH & Co. D-79849, respectively in which probes were inserted into the water column up to a depth of about 30 cm. Electrical conductivity was measured using WTW InoLab model Cond7110. Water samples for the