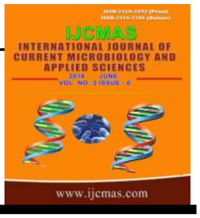

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Original Research Article

Assessment of physicochemical parameters in relation with fish ecology in Ishasha River and Lake Edward, Albertine Rift Valley, East Africa

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ABSTRACT

The present study was designed to determine the physicochemical parameters status along lower Ishasha River and littoral zone of Lake Edward, East Africa, for a period of eight months from July 2011 to May 2012. Water samples were collected on monthly basis in eight sites (river and lake) and analyzed for surface water temperature, dissolved oxygen, pH, electrical conductivity, total dissolved solids, and water transparency. These parameters were compared with water quality standards to demonstrate their ability to support fish species in selected sites. Analysis showed longitudinal differences ($p < 0.05$) along the river. Water was slightly cool, well oxygenated and alkaline at upstream; and contained much more TDS and EC at downstream, indicating the impact of agriculture and deforestation on the river. In the littoral zone, except for DO, all parameters differed ($p < 0.05$) from site to site; owing to differences in effluent inputs from respective outlets. In overall, the mean values of the parameters remained within the safe limits of water quality standards during the study period in all sites; revealing that physicochemical parameters in these habitats were permissible for most aquatic species. But, measures should be taken to regulate agricultural and deforestation activities upriver to avoid advert conditions.

Keywords

Physico-chemical parameters, water quality, Ishasha River, Lake Edward, Albertine Rift Valley

Introduction

Lakes and rivers are very important part of our natural heritage. They have widely been utilized by mankind over the centuries to the extent that very few, if not many are now in a natural condition (Furhan Iqbal *et al.*, 2004; Adakole *et al.*, 2008). The maintenance of healthy aquatic ecosystem is dependent on the physicochemical properties and biological diversity (Venkatesharaju *et al.*, 2010).

The interactions of both the physical and chemical properties of water play a significant role in composition, distribution, abundance, movements and diversity of aquatic organisms (Mustapha and Omotosho, 2005; Sangpal *et al.*, 2011; Murungan and Prabaharn, 2012; Deepak and Singh, 2014). To minimize energy expended for survival, species typically favor habitat conditions that optimize their physiology process (Matthews, 1990).

In particular, fish populations are highly dependent upon the variations of physicochemical characteristics of their aquatic habitat which supports their biological functions (Mushahida-Al-Noor and Kamruzzaman, 2013, Whitfield 1998; Albaret 1999; Blaber, 2000; Jeffries and Mills, 1990; Furhan Iqbal *et al.*, 2004; Ali, 1999; Koloanda and Oladimeji, 2004; Ojutiku and Kolo, 2011). Among the physicochemical factors, temperature, Dissolved Oxygen, pH, turbidity, water transparency and current among others, and their regular or irregular fluctuations, have been identified as determinants in riverine fish ecology (Boyd, 1998; Whitfield 1998; Ali, 1999; Albaret, 1999; Blaber, 2000; Thirumala *et al.*, 2011; Mushahida-Al-Noor and Kamruzzaman, 2013).

Marshall and Elliot (1998), noted significant correlations between a number of individual fish species and water temperature, salinity, dissolved oxygen and depth. Blaber and Blaber (1980) reported that turbidity is associated with productive feeding areas and provides cover for fishes. Other studies have determined that fish move away from alkaline waters when pH levels approach 9.06 – 10.0, unless more important survival factors outweigh avoidance, including food availability or lower predation levels (Serafy and Harrel, 1993; Scott *et al.*, 2005). These factors are responsible for distribution of organisms in different fresh water habitats according to their adaptations, which allow them to survive in a specific habitat (Jeffries and Mills, 1990).

Lakes and rivers in the Albertine Rift Valley, East Africa, are known for their exceptional biodiversity (Lowe-McConnell, 1987; Kurt and Hecky, 1987; Coulter, 1991; Snoeks, 1991; 1994; Hori *et al.*, 1993; Nakai *et al.*, 1994; Plumptre *et al.*, 2003, 2004), for example Lake Tanganyika, with unique and many endemic species (Fryer and Iles, 1972; Thys van Audenaerde *et al.*, 1980; Lowe-McConnell, 1987; Kurt and Hecky, 1987; Brichard, 1989; Coulter, 1991; Snoeks, 1991; 1994; Hori *et al.*, 1993; Nakai *et al.*, 1994). Although abundant, rivers of the Albertine Rift valley have received little research attention from ecologists and remain largely unknown in many respects (Lehman, 2002). Many of these rivers are also believed to provide important spawning grounds for commercially important lake fishes (Lowe-McConnell, 1987; ICNC, 1972).

Virtually, very little direct measurements are available (Lehman, 2002; Kasangaki, 2007; Kasangaki *et al.*, 2008; Mbalassa, 2008; Bagalwa *et al.*, 2014) for the water chemistry of rivers draining into Lake Edward in the Albertine Rift valley. Some chemical measurements done in several bays and river deltas (Damas, 1937; Marlier, 1951, 1954) showed that, nutrient concentrations found in Lake Edward over years, were highly influenced by the fluvial inputs to the lake (Lehman, 2002). According to Kilham (1984), Lake Edward and all of the lakes of the Albertine Rift valley are ecologically and evolutionary influenced by their affluent inputs.

Despite their ecological and evolutionary roles, the real ecology and chemistry of the rivers that flow into Lake Edward is essentially unknown and unmeasured (Kilham, 1984; Lehman, 2002). One such affluent is Ishasha River at the Republic Democratic of Congo - Uganda border in the Bwindi, Virunga and Queen Elizabeth National Parks. Recent ecological studies in some rivers, including Ishasha River have made a contribution to the understanding of the ecological aspects such as fish diversity (Kasangaki, 2007; Mbalassa, 2008) and the impacts of exogenous inputs into the riverine benthic communities (Kasangaki *et al.*, 2008).

Ishasha River is of immense significance in terms of ecological services, fisheries resources and, economic benefits to communities around Lake Edward Basin. It runs through four protected areas namely Mgahinga, Bwindi, Queen Elizabeth and Virunga National Parks, before it pours into Lake Edward (Beadle, 1981). These protected areas are among the critical world heritage sites and biosphere reserves (IUCN, 1997; 2001; 2002). Ishasha is believed to provide feeding and spawning grounds for migratory fish species from Lake Edward (ICNC, 1972; Mbalassa, 2008). The river is also important to the people of the areas; it is used as source of water and fish, and contributes to livelihood sustenance of the local communities. Because of its role as spawning grounds for fish, its downstream habitats are considered sensitive and should be protected from human disturbance (ICNC, 1972).

There is no doubt that fish are driven by their physicochemical surroundings to areas that are physiologically optimal (Beadle, 1981). An analysis of the physicochemical parameters is necessary to understand ecological and environmental pathways of Lake Edward aquatic resources. The objective of this study was to determine the physicochemical parameters in lower Ishasha River and Lake Edward for their ability to support aquatic species, especially fish in the selected sites.

Materials and Methods

Study site

Lake Edward is a natural border of the Democratic Republic of Congo (DR Congo) and Uganda in the Albertine Rift region (Fig.1). The lake is located at 912 m of altitude, between 29^o 15’ and 29^o 55’ East and 0^o 45’ South (Verbeke, 1957; Beadle 1981). Its watershed drains a total area of about 2, 250 km^2 (Damas, 1937). The lake has a maximum length of about 80 km and the maximum width of about 40 km, with the maximum depth estimated at 117m, while the mean depth is about 40 m, and water volume of approximately 90 km^3 (Damas, 1937; Verbeke, 1957). The climate is tropical with bimodal rainfall distribution. The dry season spans from December to February and June to August and the rainy season from March to May and September to November. The annual rainfall varies from 650 - 900mm (Verbeke, 1957; Beadle, 1981). The monthly mean maxima of temperature vary from 26.3^{o}C in January to 30^{o}C in September, while the minima vary from 15.5^{o}C to 17.8^{o}C. The absolute maximum temperature is of 32^{o}C generally in February, and the absolute minimum temperature is of 14^{o}C generally recorded in January, February, June and July (Damas, 1937; Verbeke, 1957). The watershed has many tributaries, major ones being Ishasha, Rutshuru, and Rwindi

Rivers from the Virunga Volcanoes in the southeast of the lake in the DR Congo side and Ntungwe, Nchwera, Rwampunu, Nyamweru Rivers and Nyamugasani river (from Ruwenzori highlands), and Kazinga channel in northeast of the lake in the Uganda side (Figure 1). Ishasha River runs through four protected areas namely Mgahinga, Bwindi, Queen Elizabeth and Virunga National Parks before it pours into the lake (Beadle, 1981). These protected areas are vital components for conserving and managing freshwater resources, ecosystems and biodiversity of the Albertine Rift Valley (Plumptre *et al.*, 2003, 2004).

Fig.1: Study area and sampling sites (in red) along Lower Ishasha River and in the littoral zone of Lake Edward, in Virunga and Queen Elizabeth National Parks, Albertine Rift Valley. The sampling sites in the river were established based on their accessibility and the level of human impact. Five sites were selected along the river; these include Kinyozo (upstream), Lulimbi (middle stretch), Kagezi I, Kagezi II and Kagezi III (River mouths). Kagezi I, II, and III sites form a delta of river mouths of the Ishasha River distant of 3 km in average from each other, pouring into Lake Edward. In the littoral zone, three sites namely Kagezi I-littoral, Kagezi II-littoral, and Kagezi III-littoral were selected based on the level of interaction between the river and the lake (Fig. 1).

Water Sampling

Water sampling was carried out in July – August and September – October 2011 and in February –March and April - May 2012. At each site, sampling was done twice a month and each day, measurements were taken between 6:00 - 9:00 in the morning, and between 4:00 - 6:00 in the evening. In the river, measurements were done within a 200 meter sampling-stretch in the middle of section of the river at surface water. In the lake, measurements were done within 500 meters in the littoral zone from the river mouths. At this distance, waters from the two ecosystems (river and lake) were assumed to be completely mixed. Physicochemical parameters including water surface temperature (T^o), pH, electrical conductivity (EC), and the total dissolved solid (TDS) were directly measured using the HI 98129 Combo pH & EC/TDS meter. Water transparency (TRA) was evaluated using a black & white Secchi Disc Wildco (P/N 58-B20, S/N2710). The content of dissolved oxygen (DO) at each site was assessed with the aid of the DO Meter (YSI55). The analysis of variance (ANOVA) was run to compare the variations in physicochemical parameters between sites. The Pearson’s correlation ‘r” was performed to determine affinities among the physicochemical parameters using Past3 Software. All the parameters were compared with water quality standards (Boyd and Tucker, 1998; Ali *et al.*, 2000) in relation to their suitability to sustain aquatic species in the selected sites.

Results and Discussion

The mean values of water physicochemical parameters in selected sites along the Lower Ishasha River and their correlation analysis are presented in the tables 1and 2, respectively.

Some parameter such as surface temperature was found relatively consistent in sampling sites of rivers. Little, but significant (F = 2.665, $p < 0.05$) variations were detected between the sites. Water appeared to be relatively warm around Lulimbi (middle stretch), followed by the water around Kagezi III and II river months. While, water was found to be cool around Kagezi I river mouth compared to other sites.

The content of dissolved oxygen (DO) in the water differed significantly between sampling sites (F = 74.96, $p < 0.05$). Therefore, the water around Kinyozo (upper stretch) and Lulimbi (middle stretch) contained much more DO than the rest of the sites. The maximum DO recorded in these sites was about 6.9 mg/L in Lulimbi and the lowest DO was recorded in Kagezi II (1.36 mg/L). The results show that the upstream sampling sites, namely Kinyozo and Lulimbi contained high content of DO than the downstream ones, including Kagezi I, II and III river mouths.

The water status showed very significant variation in pH values between the sites (F = 33.28, $p < 0.05$). However, the water was found to be alkaline in Kinyozo and Lulimbi with 7.33±0.09 and 7.02±0.07 values of pH, respectively. Whereas, in Kagezi I, II, and III river mouths water was found to be acidic with 6.3 ± 0.03, 6.57±0.08, and 6.60±0.03 values of pH respectively.

The content of TDS (F = 20.49, $p < 0.05$) in water and the level of water EC (F = 22.49, $p < 0.05$) varied significantly between the sites. The table shows that among the sites, Kagezi II contained high quantity of TDS (52.87±1.98 mg/l) compared to other sites. This was followed by Kagezi III and Kagezi II with averages of about 45.62±2.02 mg/l and 40.75±0.82 mg/l respectively. Water around Lulimbi contained less TDS (31.2±2.24 mg/l) than others sites. The results show that, the water from the three sites Kagezi I, II, and III contained high content of TDS and high level of EC compared to Kinyozo and Lulimbi. The three sites, being located at the downstream of the river, they receive runoff from upriver which brings sediment loads and organic matter from the heavily agricultural lands and deforested areas from adjacent headwaters of the river.

Water transparency varied significantly along the river (F = 22.65, $p < 0.05$). Therefore, at Kagezi I river, mouth water was much clearer than in other sites, this was followed by the water at Kagezi III and Kagezi II river mouths, measuring in average 58.87±3.62 cm, 53.25±5.13 cm, and 43.81±1.71 cm, respectively. At Lulimbi and Kinyozo, water appeared more turbid, measuring in average 12.8±0.94 cm and 19.17±1.59 cm, respectively.

Person's r correlation in these different sites about the selected limnological parameters is presented in table 2. The Pearson's r correlation analysis allowed noticing that, some parameters along the river flow were strongly positively or negatively correlated between them. A strong and significant correlation was found between the concentration of DO and the level pH (r = 0.89, $p < 0.05$), very strong positive significant correlation (r = 0.99, $p < 0.05$) was found between the content of TDS and the level of EC along the rivers. Positive correlations were also found between water transparency and the content of TDS (r = 0.68), and the level of EC (r = 0.63).

However, strong and negative correlations were found between the concentration of DO and the content of TDS (r = - 0.86, $p < 0.05$), level of EC (r = - 0.83, $p < 0.05$), and between the concentration of DO and the level of water transparency (r = - 0.94, $p < 0.05$). Negative correlations were also found between the variation of T^o and the content of TDS (r = - 0.08, $p > 0.05$), level of EC (r = - 0.06, $p > 0.05$), and between the variation in T^o and the level of water transparency (r = - 0.43, $p > 0.05$). Negative correlations were again found between the value of pH and the content of TDS (r = - 0.61, $p > 0.05$), level of EC (r = - 0.59, $p > 0.05$), and between the value of pH and the level of water transparency (r = - 0.90, $p < 0.05$) along the lower Ishasha River.

The limnological parameters measured in the littoral sites in the Lake Edward and their correlation analysis are presented in table 3 and 4, respectively. The temperature of the surface water in littoral zone was in general high in all selected sites, but with significant variation between the sites (F = 4.704, $p < 0.05$). The results show that water around Kagezi III-littoral zone was much warm (27.55±0.19 ^{o}C); whereas water around Kagezi I-littoral was slightly cool (25.59±0.62 ^{o}C). The difference in DO concentration was not significant between selected sites (F = 2. 273, $p > 0.05$) in the littoral zone. It was noticed that, water around Kagezi III-littoral zone contained high DO (5.16±0.36 mg/l); followed by water around Kagezi I-littoral zone (4.01±0.66 mg/l). Whereas around Kagezi II-littoral zone contained relatively less DO (3.80±0.36 mg/l).

Water was generally alkaline in all the selected sites, but the level of pH fluctuated significantly between the sites (F = 9. 536, $p < 0.05$). Water around Kagezi III-littoral zone had slightly a high level of pH (8.88±0.02) than other sites, followed by water around Kagezi II-littoral zone (8.78±0.05), and then by water around Kagezi I zone (7.62±0.32).

The quantity of TDS fluctuated significantly between the selected sites (F = 7. 313, $p < 0.05$). The results shows that water around Kagezi III-littoral zone contained much TDS, measuring in average about 361.12±1.47 mg/l; this was followed by water around Kagezi II-littoral zone with 297.25±17.54 mg/l. However, the water around Kagezi I-littoral zone measured less TDS (212.56±44.36 mg/l) compared to the rest of sites. The level of water EC varied significantly from site to site (F = 7.049, $p < 0.05$). High level of EC was found in water around Kagezi III-littoral zone (718.31±4.15 µm/cm), followed by water around Kagezi II-littoral zone, with 589.50±17.54 µm/cm and Kagezi I-littoral zone with 426.18±88.65 µm/cm.

Water transparency varied significantly between the sites (F = 7.462, $p < 0.05$), water around Kagezi III-littoral zone was much more transparent up to 108.56±10.67 cm deep, followed by water around Kagezi II-littoral zone (82.56±6.68 cm deep) and Kagezi I-littoral zone at only 64.87±5.95 cm deep. Person's r correlation in the littoral sites is presented in table 4.

In the littoral zone, all the parameters analyzed were found positively strongly correlated between them. Strong, positive and significant correlations were found between temperature and DO, pH, TDS, EC and TRA. pH is also strongly positive correlated with TDS, EC and TRA, where TDS is strongly correlated with EC and TRA. There is also a strong positive correlation between EC and TRA. For DO with other parameters there are positive correlations.

The temperature values recorded in all sampling sites in both river and littoral zone were generally high, and varied between 22.62±0.16^{o}C - 23.8±0.40°C (river) and 25.59±0.62^{o}C - 27.55±0.19^{o}C (lake), although little variations were observed between sites, temperatures fitted within the limits standards (Colman *et al*., 1992; Boyd, 1998). The present trend has already been acknowledged by Lowe-McConnell (1987), and pointed out that tropical regions are characterized by high temperatures with relatively little variations. For example, the temperatures of Lake Victoria were found fluctuating between 23°C and 26°C throughout the year (Lowe-McConnell, 1992). Temperature is known to have a significant effect not only on the biological functions of the aquatic organisms, but also on other physicochemical parameters (Beadle, 1981; Huet, 1986; Lowe-McConnell, 1987; Colman *et al*., 1992; Boyd, 1998). However, Kasangaki *et al.* (2008) found out that, temperature, pH, and water transparency were among the most important factors predicting benthic macro-invertebrate assemblages in the upper Ishasha River.

In most of tropical water systems, species grow best at temperature between 20 ^{o}C and 32 ^{o}C and water temperatures generally remain in this range year-round (Lowe-McConnell, 1987; Boyd, 1998). Temperature values recorded during the study period corroborated with the values found by Bagalwa *et al*. 2014 and those reported by Damas (1937), Marlier (1951, 1954), Verbeke (1957) and Lehman (2002) in the same areas. The later reported that the monthly mean fluctuations in temperature values ranged between 20 to 26^{o}C. They further revealed that, cloud cover and wind speed were by far the most influencing climatic factors of the temperature in the region. In respect to our findings with regards to the temperature conditions, lower Ishasha River and Lake Edward were proved to provide some of the best habitats for the biological functions of aquatic species in these water systems. In the littoral zone, strong correlations were related between water temperature and other factors such as DO, pH, TDS and EC. Tassaduqe *et al.* (2003) also found that the levels of pH and dissolve solids in the Indus River, Pakistan were directly related to the water temperature. However, temperature is known by far as the most critical factor influencing both aquatic life and other physicochemical parameters in the water system (Huet, 1986; Colman *et al*., 1992; Boyd, 1998).

Among the dissolved gases, the dissolved oxygen plays the most important role with regard to the water quality. It is critical for aquatic organisms' respiration (Colman *et al*., 1992). Therefore, the dissolved oxygen is among determining factors for the survival and the growth of aquatic organisms. In the present study, DO showed high values (> 5 mgl^{-1}) in the upstream sites, indicating that it was within the permissible limits for aquatic lives; whereas DO values were close to the minimum limit at the downstream sites. The content of DO showed an inverse longitudinal pattern to the river flow gradient. This could result from the fact that, at the upstream sites (Kinyozo and Lulimbi); the river crosses along savannah grassland area, and receives a direct sunlight which is known to influence the increase of photosynthesis rate (Boyd, 1998). The photosynthesis rate combining with the water turbulence, could be among factors contributing to the higher oxygen content recorded upstream. Wootton (1992) and Maitland and Morgan (1998) revealed that, the upper stretches of rivers are usually characterized by well-oxygenated water and a current sufficiently high. The lower content of DO recorded at the downstream sites, could result from the decomposition of large amount of organic matter from high density of aquatic plants covering the river mouths around these sites. A study by Boyd (1998) found out that, in tropical waters the rate of DO consumption by decaying organic matter is greater. DO showed direct relation with pH along the river. The reason could be that the decomposition of organic matter is believed to release amounts of humic acids during mineralization that keep water acidic and thereby decreases the pH. Lowe-McConnell (1987) stated that decomposing vegetal debris generally makes the water acidic. At the same, the DO decreases due to its uptake by decomposing organisms like bacteria (Boyd, 1998). This could explain the high and significant correlation (r) found between the content of DO and the level of pH along the Lower Ishasha River.

In the littoral zone, the content of DO was slightly lower than the safe limits (< $5mgl^{-1}$) at two sites (Kagezi I & II). While at Kagezi III, DO was within the safe limits. In the littoral zone, dissolved oxygen showed negative relationship with total dissolved suspensions, water conductivity and transparency. However, water turbidity is known among major factors decreasing water transparency. The turbidity also affects the penetration of the sunlight into water (Maitland and Morgan, 1997) and thereby reduces the photosynthetic rate in water, which in turn could reduce the DO content. The results show that, though water contained DO sufficient to support many aquatic lives in the selected sites, relative variation in its content was detected from site to site, suggesting that DO is subject to spatial/local variations within the lower Ishasha and littoral zone Lake Edward.

One of the major indicators of the water quality, after the dissolved gases (O_2 and CO_2), is the ionic composition of water, of which most important measure is the pH (Colman *et al.*, 1992). The pH is known to influence the physiological functions of fish and other aquatic lives. In upper Ishasha River, pH was among the most important factors predicting benthic macro-invertebrate assemblages (Kasangaki *et al.*, 2008). Around a pH 7, the nutrients are easily assimilated by most of the plant organisms and the food chain can develop normally (Colman *et al.*, 1992). In turn this allows a good growth of fish species, among others. The pH of water is important because many biological activities can occur only within a narrow range (Tassaduqe *et al.*, 2003). Thus, pH range for diverse fish production is between 6.5 and 9 (Boyd and Tucker, 1998; Ali *et al.*, 2000). Any variation beyond acceptable range could be fatal to many aquatic organisms (Furhan Iqbal *et al.*, 2004).

In the present study, upstream sites showed high values of pH than the downstream ones. High values of pH at upstream sites (Kinyozo and Lulimbi) may be caused by the combined effect of low alkalinity and high surface water temperature (Marlier, 1954). Whereas, the acidic pH recorded at downstream sites (Kagezi I, II & III) may be influenced by the presence of humic acids from the decomposition of *Papyrus* and organic matters from other macrophytes on the river banks (Lowe-McConnell, 1987). But, even though, all the values of pH measured along lower Ishasha river channel set within the limits of standard ranges, therefore suitable for production of fish and most of aquatic lives. The pH range in the littoral zone varied within the favourable range, showing the littoral zone as suitable for fish production. The present pH values confirm those reported in previous studies (Damas 1937; Marlier 1951, 1954; Verbeke, 1957; Lehman, 2002; Bagalwa et al. 2014) in the same lake.

Total dissolved solids indicate the total amount of inorganic chemicals in solution (Colman et al., 1992; Furhan Iqbal *et al.*, 2004). A maximum value of 400 mg L^{-1} of total dissolved solids is permissible for diverse fish population (Boyd and Tucker, 1998; Ali *et al.*, 2000). From the results of this study, TDS content for both river channel and the littoral zone of Lake Edward was within the permissible limits, demonstrating that these habitats are favorable for aquatic biodiversity. Indeed many ecologists have revealed a positive correlation between total dissolved solids and turbidity (Chaudhry et al., 1990; Salam & Rizvi, 1999; Furhan Iqbal *et al.*, 2004). Turbidity is known to have a negative influence on aquatic diversity, distribution and abundance (Cohen *et al.*, 1993).

The turbidity affects the respiratory capacity of fish and the photosynthetic activities of the plant organisms (Colman *et al.*, 1992). However, according to Blaber (2000), turbidity can affect fishes in three main ways: it may afford greater protection for juvenile fish from predators; it is generally associated with areas where there is an abundance of food; and it may provide an orientation mechanism for migration to and from the river. Despite its ecological value, excessively high water turbidity has been proved to affect fish egg survival, hatching success, feeding efficiency (mainly of filter feeders), growth rate and population size (Whitfield 1998). In the present study, the water EC was found highly correlated to the TDS along the river, and to the TDS, T°, pH among others in the littoral zone. However, several factors influence the conductivity including temperature, ionic mobility and ionic valences (Boyd, 1998; Furhan Iqbal *et al.*, 2004). In turn, conductivity provides a rapid mean of obtaining approximate knowledge of total dissolved solids concentration and salinity of water sample (Odum, 1971). Both, the suspended solids and turbidity affect the penetration of light under water (Maitland and Morgan, 1997; Furhan Iqbal *et al.*, 2004).

Light penetration varying from 30 cm to above 60 cm was acknowledged to be favourable for fish production (Boyd and Tucker, 1998; Ali *et al.*, 2000). However, in this study the estimated values of water transparency were within the permissible limits (43.81±1.71 cm -108.56±10.67 cm), in all downstream and littoral sites. On the contrary, water transparency in upstream sites was below the limits (12.8±0.94 cm - 19.17±1.59 cm). Therefore, lower values of water transparency observed in the upstream sites could be related to the intensive agricultural activities along the river catchment, among others.

Heavy cultivation along with deforestation was permanently observed on the hills with steep slopes of the river affluents and on the river head waters during the study periods. The runoff from the cultivation and uncovered hill flanks could drain subsequent sediment which in turn decreases water transparency in the river. Maitland and Morgan (1997) stated that the clearing of forests for agriculture also increases the runoff of surface water and the rate of soil erosion with subsequent silting in the waters draining such areas. Accordingly, Moss (1988) found out that *Papyrus* and other macrophytes inside the river and on the riverbanks, act as huge filters for silt and change chemical composition of the water passing through. Kasangaki *et al.* (2008) found out that, the agricultural and deforested sites in the upper Ishasha River generally had low transparency values compared to the sites located in the forest and boundary habitats. They also revealed that water transparency was among the most important factors predicting benthic macro-invertebrate assemblages in the upper Ishasha River.

Fig.1 Study area and sampling sites (in red) along Lower Ishasha River and in the littoral zone of Lake Edward, in Virunga and Queen Elizabeth National Parks, Albertine Rift Valley

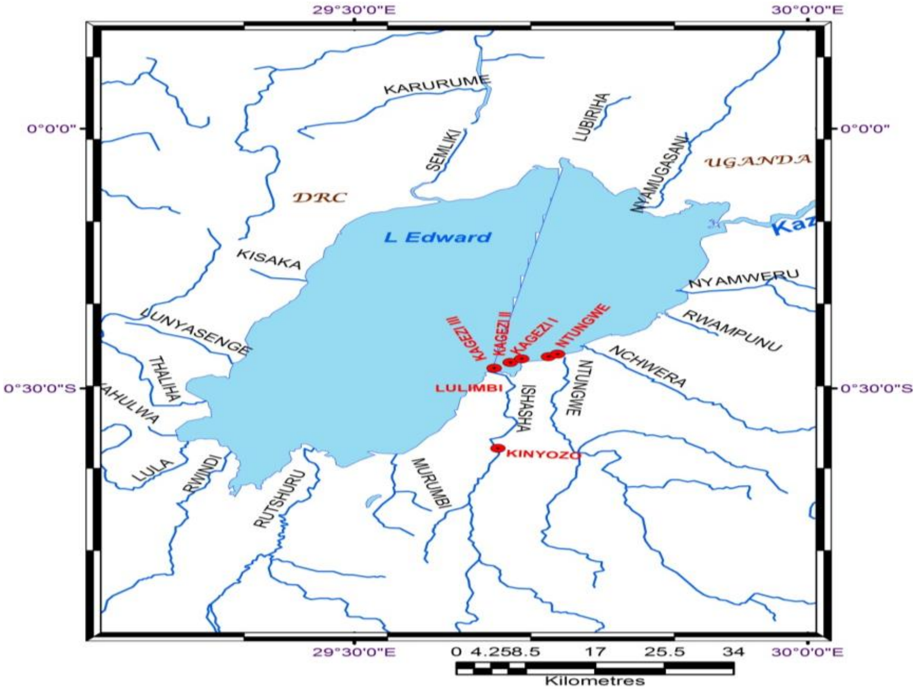

Table.1 Mean values (Mean±SE) of water physicochemical parameters in selected sites along the lower Ishasha River, Albertine Rift region

	Sites					
Parameters	Kinyozo (RC)	Lulimbi (RC)	Kagezi I (RM)	Kagezi II (RM)	Kagezi III (RM)	STRDS
T^o (^{o}C)	23.04±0.55	23.8±0.40	22.62±0.16	23.35±0.11	23.60±0.17	20-32
DO (mg/l)	6.64±0.17	6.9±0.54	1.91±0.30	1.36±0.15	1.55±0.03	> 1≥ 5
pH	7.33±0.09	7.02±0.07	6.34±0.03	6.57±0.08	6.60±0.03	6.5 -9
TDS (mg/l)	36.33±1.65	31.2±2.24	40.75±0.82	52.87±1.98	45.62±2.02	≤ 400
EC µS/cm	73±3.32	62.7±4.56	82.12±1.89	112.5±4.86	91.68±4.15	20-1500
TRA (cm)	19.17±1.59	12.8±0.94	58.87±3.62	43.81±1.71	53.25±5.13	> 30 - 60

Legend: SE: Standard Error, RC: River channel; RM: River mouth; STRDS: Standards of water quality (Boyd and Tucker, 1998; Ali *et al.*, 2000)

Table.2 Pearson's r correlation between parameters in different sites along the lower Ishasha River, Albertine Rift Valley

	T°	DO	pH	TDS	EC	TRA
T°	1					
DO	0.23	1				
pH	0.27	*0.89	1			
TDS	-0.08	*-0.86	-0.61	1		
EC	-0.06	*-0.83	-0.59	*0.99	1	
TRA	-0.43	*-0.94	*-0.90	0.68	0.63	1

Note: * = significant correlation at 0.05

Table.3 Mean values (Mean±SE) of water physicochemical parameters in littoral zone of Lake Edward, Albertine Rift Valley

Parameters	Kagezi I-Litt	Kagezi II-Litt	Kagezi III-Litt	STRDS
T° (°C)	25.59±0.62	26.42±0.43	27.55±0.19	20-32
DO (mg/l)	4.01±0.66	3.80±0.36	5.16±0.36	> 1≥ 5
pH	7.62±0.32	8.24±0.14	8.88±0.02	6.5 -9
TDS (mg/l)	212.56±44.36	297.25±17.54	361.12±1.47	≤ 400
EC µS/cm	426.18±88.65	589.50±35.28	718.31±4.15	20-1500
TRA (cm)	64.87±5.95	82.56±6.68	108.56±10.67	30 -60

Legend: SE: Standard Error, Litt: Littoral zone; STRDS: Standards of water quality (Boyd and Tucker, 1998; Ali *et al.*, 2000)

Table.4 Pearson's r correlation between parameters in the littoral zone of Lake Edward

	T°	DO	pH	TDS	EC	TRA
T°	1					
DO	0.83	1				
pH	*0.99	0.78	1			
TDS	0.98	0.73	*0.99	1		
EC	0.98	0.74	*0.99	*0.99	1	
TRA	*0.99	0.85	0.99	0.98	0.98	1

The assessment study of water quality in the lower Ishasha River and littoral zone of Lake Edward showed longitudinal variations in the studied physicochemical parameters along the lower Ishasha River. The different parameters used in the study revealed that water quality in both Ishasha River and Lake Edward are within what is considered to be safe limits and good to support the survival and production of aquatic life especially fish. The results suggest that, although physicochemical parameters in these habitats were suitable for most aquatic species, they were subject to high longitudinal variations. The variations detected could reach adverse conditions if any measure is not taken to regulate agricultural activities on the river banks and deforestation on headwater areas of the river into the lake. This must be taken into account to ensure the conservation of these critical aquatic ecosystems.

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