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Effects of the Bujagali Hydropower Project on Major Physico-Chemical Parameters of the Upper Victoria Nile Water in Uganda, East Africa

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Abstract
The Bujagali hydropower project is a 250 megawatt facility that was set up to alleviate power shortages in Uganda. The project was perceived to have negative effects on major physico-chemical characteristics of the upper Victoria Nile water. Key water physico-chemical parameters monitored biannually in April and September from 2006 to 2015 at the upstream and downstream transects and in the reservoir were dissolved oxygen, pH, temperature, TSS, oil/grease, conductivity and water clarity. Triplicate water samples for TSS plus oil and grease were analyzed from the laboratory following standard procedures. The rest of the parameters were determined in-situ using a CTD profiler. Reference for environmental compliance was made to NEMA and EU/WHO environmental discharge standards. All parameters were within acceptable limits i.e. dissolved oxygen (>3 mgl^{-1}); temperature (20 to 35 °C); TSS (<100 mgl^{-1}); oil and grease (<10 mgl^{-1}), and pH (6 to 8.5). Thus, the Bujagali hydropower project had so far had no significant negative effects on the major physico-chemical parameters of the upper Victoria Nile water. Continued monitoring is recommended to enable detection of any deviations, if any, from the observed trends.

Keywords: Bujagali, Environmental standards, Hydropower, Physico-chemical parameters

Introduction

From the beginning of the twentieth century, technological progress and a greater need for energy, water supply, and flood control have motivated an increase in the number of hydropower plants and dams constructed all over the world (Horlacher *et al*., 2012). The world over, hydropower has traditionally been considered environmentally friendly because it represents a clean and renewable source of energy (Birgitta *et al*., 2010; Kothari *et al.*, 2010; Panwar *et al.*, 2011; Abanda, 2012). This is because production of this form of energy does not significantly contribute to acid rain that results into alteration of water quality characteristics. This form of energy is renewable in that the hydrologic cycle circulates water back to wetlands, rivers, streams, lakes and oceans (Chahine, 1992; Bullock and Acreman, 2003; Narasimhan 2009; Seager *et al.*, 2010; Wild and Liepert, 2010; Zhou *et al.*, 2011). While there are many benefits to using hydropower as a renewable source of energy, there are also environmental impacts that relate to how a hydropower project affects a river's ecosystem and associated habitats (Baxter, 1977; Anderson *et al.*, 2006; Klaver *et al.*, 2007; Rehn, 2009; Räsänen *et al.* 2012). For example, reservoirs alter riverine dynamics and can impact the water quality of the natural system (Ashby, 2009).

Hydropower dams may be a significant source of water pollution (Berkun, 2010; Zhang *et al.*, 2014; Chen *et al.*, 2015). Various scholars have long acknowledged that hydropower dams cause ecosystem pollution by altering the temperature and other physico-chemical characteristics of water that is impounded behind and released through dams, harming the biological integrity of river ecosystems (Gore *et al.*, 1989; Hasler *et al.*, 2009; Rehn, 2009; Xiaoyan *et al.*, 2010; Pandit and Grumbine, 2012; Li *et al.*, 2013; Skalak *et al.*, 2013). Worse still, the cumulative impacts of multiple hydropower dams are often much greater than the simple sum of their direct impacts (Gergel, 2002; Berkun, 2010; Birkel *et al.*, 2014). A series of dams can severely impact an entire watershed (Kibler and Tullos, 2013), even if each of the individual dams may have a relatively low impact when considered in isolation. The extent of this damage can be much greater when combined with a whole host of other threats to rivers such as poor water quality, a growing demand for scarce water, encroaching urbanization, and poor land management practices (Nel *et al.*, 2007; Tockner *et al.*, 2010). It should also be noted that the main environmental effect on the river system for hydropower operations is the alteration of flow regime which affects the water quality and cause impacts on aquatic ecosystems (Bhatt and Khanal, 2012).

The Bujagali Hydropower Project is a scheme that was set up to create substantial benefits to Ugandans such as increased supply of reliable hydroelectricity and reduced power tariffs. The power plant and its associated dam were constructed on Dumbell Island which is approximately 8 kilometers downstream from where the river leaves Lake Victoria (Figure 1). Construction of the dam and power house at Bujagali started in June 2007 and was completed in 2012. Water flowing out of Lake Victoria passes through the Nalubaale and Kiira Hydropower dams which are upstream of the Bujagali Dam. The dam created a reservoir that extends upstream to the tailrace of the Nalubaale and Kiira facilities. The Bujagali Hydropower Dam is therefore part of the upstream series of Nalubaale and Kiira dams. Effects of the hydropower project on major physico-chemical parameters was the thrust of this study because these parameters show immediate responses to any form of perturbation right from the time of project implementation.

Materials and Methods

Bujagali Energy Limited (BEL) was constructed on the section of the Victoria Nile that lies between the upstream transect (Kalange-Makwanzi) and the downstream transect (Buyala-Kikubamutwe) (Figure 1). This section of the Victoria Nile was characterized by strong waterfalls, rapids, rocky outcrops and river bends. The hinterland along the banks of the study area had been transformed by human activities from the originally wooded savannah landscape to one dominated by small farm holdings of a variety of crops. Perennial crops especially coffee and bananas, and annual crops such as maize used to cover the river banks and islands. Similarly in the more northerly downstream sections, the river banks had been transformed into sparse human settlements and small holder farmer fields.

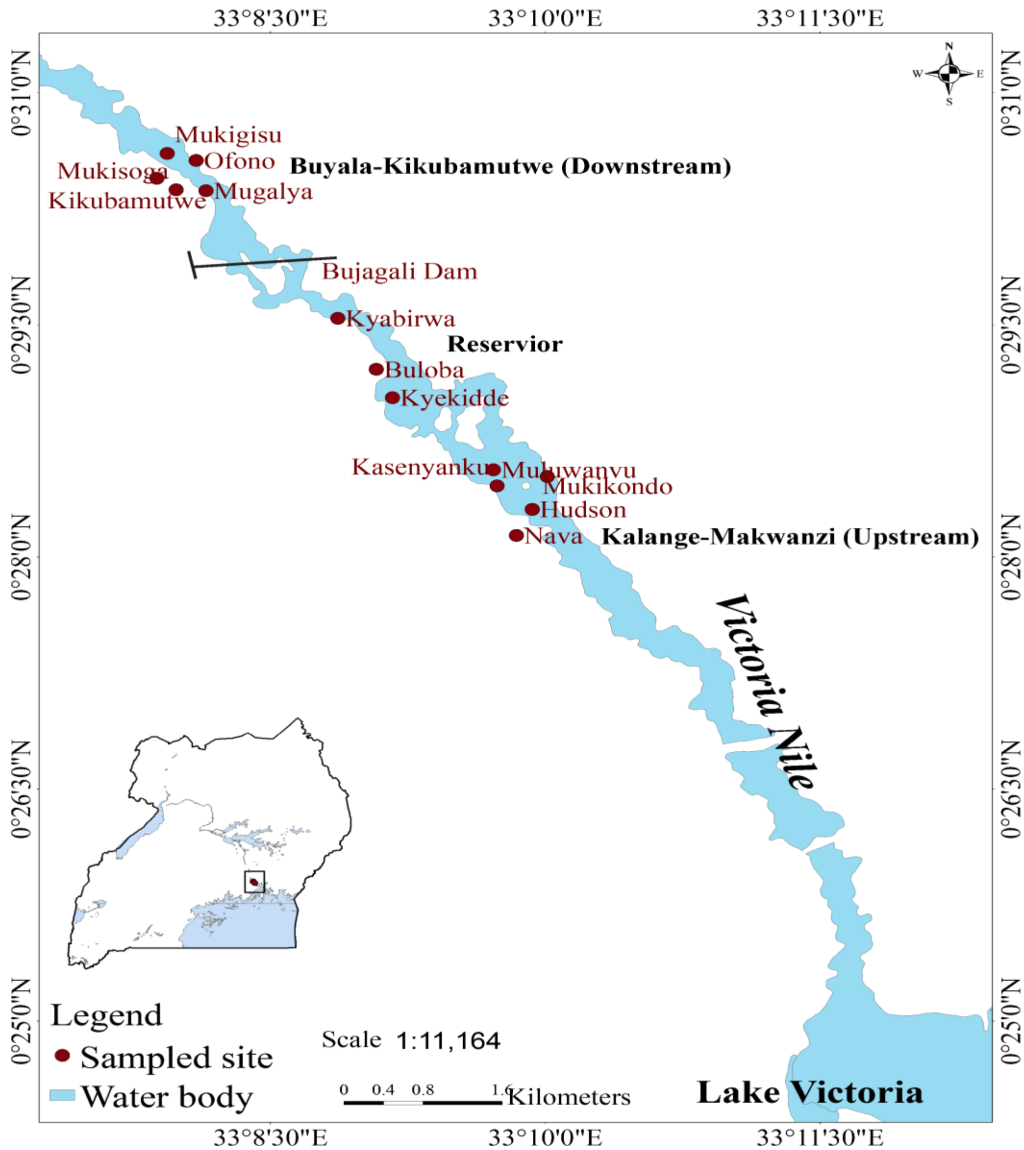

Figure 1: Map showing location of the hydropower project at Bujagali on River Nile in Uganda

The BEL reservoir is approximately 388 ha in surface area comprising of the then existing 308 ha surface of the Victoria Nile, and 80 ha of newly inundated land that is comparatively small as the reservoir water is contained within the steeply incised banks of the river. The reservoir has a maximum depth of 30 m with a mean depth of 9.3 m. This hydropower dam has a residence time of 16 hours and the reservoir's daily fluctuation was between 2 and 2.5 m. The project site is in the zone characterized by a long wet season (February to May), a short dry season (June to July), a short wet season (August to October) and a long dry season (November to January). Originally, field data collection was expected to cover all seasons in the year by sampling on a quarterly basis, but this was not feasible due to logistical constraints that dictated limiting data collection to the months of April and September of each subsequent year. These two months however, only cover the rain seasons, thus missing out the dry season data that would probably reveal seasonality effects. Thus, data was collected biannually from 2006 to 2015 during the months of April and September from the upstream and downstream of the reservoir (Figure 1). For each of the two transects (upstream and downstream), there were 153 samples i.e. 17 sampling events x 3 sites per transect x 3 (triplicates). After completing and filling the reservoir, collection of water physico-chemical data from this reservoir commenced in April 2012. Thus from the reservoir, there were 8 sampling events at 3 sites in triplicate, resulting into 72 samples. Major physico-chemical parameters were determined in three triplicates (i.e. east, middle & west of the river & reservoir) in-situ at the sub-surface between 0.5 and 1.0 m depth at each of the two transects, and integrated samples from the reservoir, using a CTD profiler (Seabird Electronics Model 19-03). In total, 153 samplings (i.e. 3 sites per transect x 3 sub-samples x 17 months) were done at each of the transects, and 72 samplings (i.e. 3 sites x 3 sub-samples x 8 months) in the reservoir. Parameters determined in-situ using a CTD profiler were dissolved oxygen, pH, temperature and water conductance. Water clarity (or secchi depth) was also determined in-situ from the shaded side of the canoe using a 25 cm diameter white Secchi Disc (Model KC Denmark A/S) following standard methods. However, Total Suspended Solids (TSS) plus oil and grease were determined in the laboratory as detailed below. All samples were well labeled with respect to site, transect and date of sampling.

Total suspended solids (TSS)

Water samples for TSS were collected as an integrated sample from the water column using a 3 L Van Dorn sampler (Wildlife Supply Company Model KC Denmark A/S) from the respective transects. 1,000 ml of each sample was put in Nalgene plastic bottles for determination of TSS concentration. Final concentrations of TSS were determined by weight difference. Here, the initial weight of an oven dried 0.45 µm GF/C Whatman filter paper was obtained before filtering a known volume of water. After filtration, the filter papers were oven dried for 1 hour at 105 ºC, left to cool to constant room temperature, and reweighed. The weight difference per volume of water filtered represented the concentration of TSS.

Oil and grease

Water samples for oil and grease were collected in the same way as those for TSS and a known volume preserved in glass bottles using hydrochloric acid and kept on ice in a cool box. Preserved water samples were delivered the same day to the National Water and Sewerage Corporation (NWSC) Laboratory in Kampala for analysis using the partio-gravimetric method as described in Greenberg *et al.* (1992).

The major objective of this study was therefore to determine the effects of the Bujagali Hydropower Project on the major physico-chemical parameters of the upper Victoria Nile water. Results from this study were expected to guide management in case of need for mitigation against significant negative effects of the project on the water environment. It was hence hypothesized that the BEL project would not have any significant negative effects on major physico-chemical parameters of the water of the upper Victoria Nile.

Data Analyses

Data were imported from excel into SPSS Statistics Data Editor Version 20.0, and analyzed using “Paired Samples T-Test” for comparison of means. In all analyses, the level of statistical significance was determined at 95% (p = 0.05) Confidence Interval.

Trends in major physico-chemical parameters are provided for the upstream and downstream transects (April and September, 2006 to 2015), and for the reservoir (April and September, 2012 to 2015) as compared with permissible environmental discharge standards by Uganda’s National Environmental Management Authority (NEMA, 1999), the World Health Organization (WHO, 1993) and the European Union (EU, 1998) (Table 1).

Table 1: NEMA, WHO and EU permissible environmental discharge standards

Parameter	**NEMA Standard**[1]	**WHO Standard**[2]	**EU Standard**[2]
Water conductance (µS cm^{-1})	-	≤250	≤ 250
Dissolved oxygen (mgl^{-1})	-	-	5.0
pH	6.0 – 8.0	6.5 – 8.5	6.5 – 8.5
Temperature (°C)	20 - 35	-	-
Water clarity (cm)	-	-	-
TSS (mgl^{-1})	≤ 100	-	-
Oil & Grease (mgl^{-1})	≤ 10	-	-

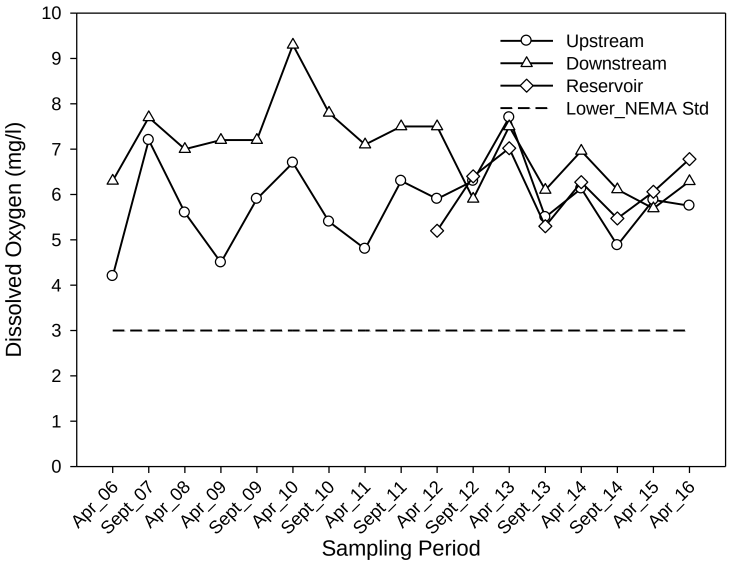

Figure 2: Trends in concentration of dissolved oxygen compared to NEMA permissible lower limit

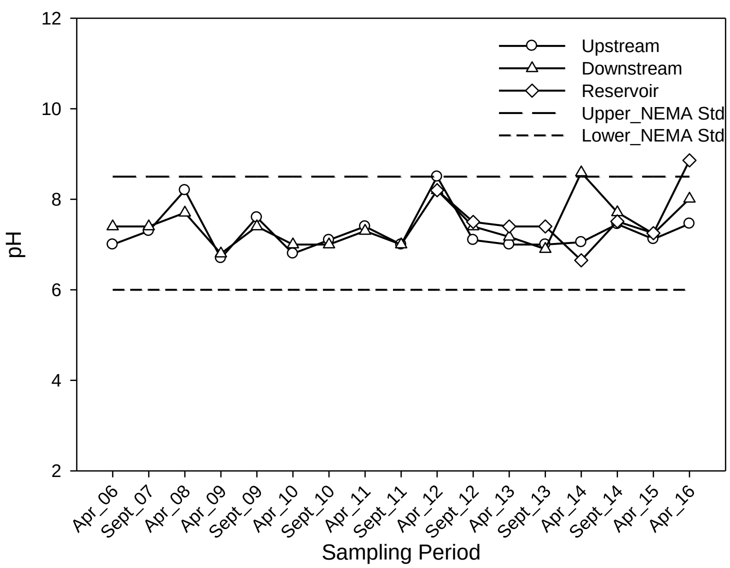

Figure 3: Trends in pH compared to NEMA permissible range

Results

Figure 2 shows trends in average values of dissolved oxygen. The lowest mean dissolved oxygen concentration was 4.2 mgl^{-1}at the upstream transect in April 2006 and was above the NEMA minimum environmental standard of 3 mgl^{-1}. There was a significant difference in average dissolved oxygen concentrations before and after completion of the dam, with significantly higher concentration at the downstream transect (M = 7.01 mgl^{-1}, SD =0.89) compared to the upstream transect (M = 5.80 mgl^{-1}, SD = .92), $t(16) = 5.00$, $p < 0.05$. However, there were no significant differences between the upstream transect (M = 5.80 mgl^{-1}, SD = 0.92) and the reservoir (M = 6.06 mgl^{-1}, SD =.68), $t(7) = 0.31$, $p > 0.05$; and between the reservoir (M = 6.06 mgl^{-1}, SD = 0.68) and the downstream transect (M = 7.01 mgl^{-1}, SD = 0.89), $t(7) = 1.31$, $p > 0.05$. At all sites, dissolved oxygen concentrations were significantly higher, $t(16)$, $p < 0.05$, compared to the minimum environmental discharge standard of 3 mgl^{-1}. Trends in pH (Figure 3) were such that most of the sampling period other than that in the reservoir in September 2015 whose mean value was above the upper permissible limit, this remained within the NEMA and WHO/EU permissible range of 6 to 8.5 even before and after completion of the dam. Despite this, there were no significant differences in pH between the upstream (M = 7.28, SD = 0.47) and downstream (M = 7.43, SD = 0.49) transects, $t(16) = 1.29$, $p > 0.05$; between the upstream transect (M = 7.28, SD = 0.47) and the reservoir (M = 7.60, SD = 0.66), $t(7)$, = 1.33, $p > 0.05$; and between the reservoir (M = 7.60, SD = 0.66) and the downstream transect (M = 7.43, SD = .49), $t(7) = 0.13$, $p > 0.05$.

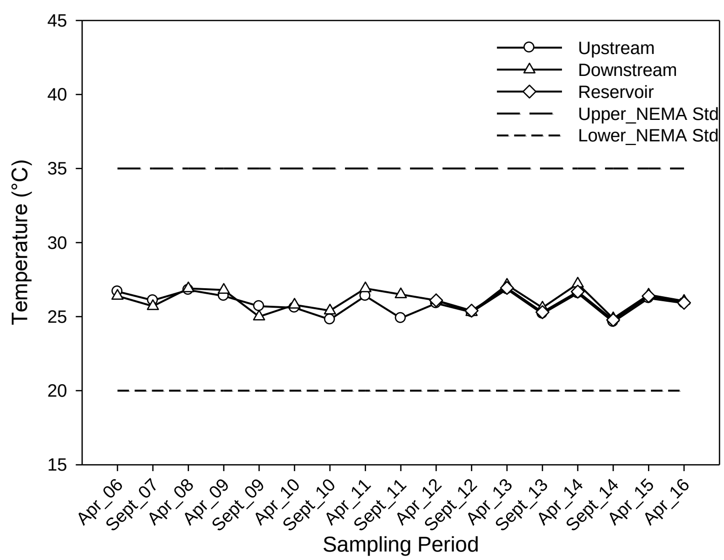

Figure 4: Trends in water temperature compared to NEMA permissible range

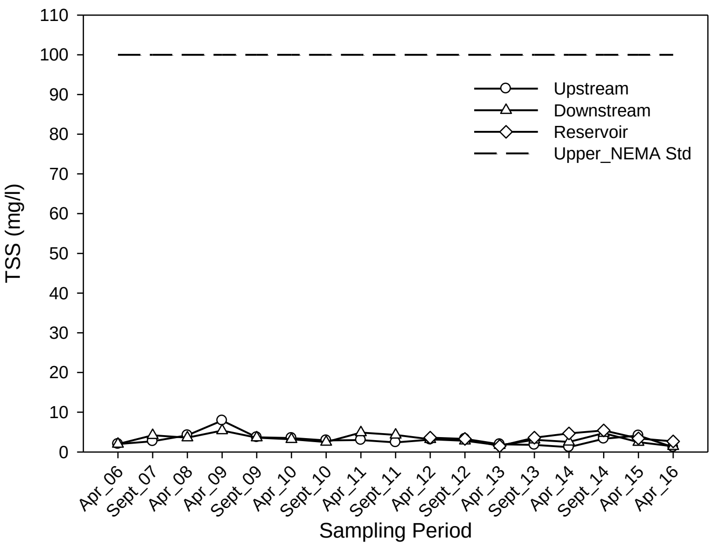

Figure 5: Trends in concentration of TSS compared to NEMA permissible upper limit

Trends in average water temperature are shown in Figure 4. Although water temperatures varied slightly among sites, mean values remained within the permissible NEMA range of 20 to 35°C. While minor variations were noted, there were no significant differences in water temperatures between the upstream (M = 25.88°C, SD = 0.72) and downstream (M = 26.13°C, SD = 0.74) transects, $t(16) = 0.40$, $p > 0.05$; between the upstream transect (M = 25.88°C, SD = 0.72) and the reservoir (M = 25.95°C, SD = 0.74), $t(7) = 1.57$, $p > 0.05$; and between the reservoir (M = 25.95°C, SD = 0.74) and the downstream transect (M = 26.13°C, SD = 0.74), $t(7) = 1.48$, $p > 0.05$. While this was so for water temperature, the concentration of TSS showed minimal variability over the sampling period and was far below the permissible upper NEMA environmental discharge standard of 100 mgl^{-1} (Figure 5). No significant differences in TSS were noted between the upstream (M = 3.08 mgl^{-1}, SD = 1.54) and downstream (M = 3.27 mgl^{-1}, SD = 1.15) transects, $t(16) = 0.68$, $p > 0.05$; and between the upstream transect (M = 3.08 mgl^{-1}, SD = 1.54) and the reservoir (M = 3.52 mgl^{-1}, SD = 1.19), $t(7) = 2.04$, $p > 0.05$. However, there was a significant different in the concentration of TSS between the reservoir (M = 3.52 mgl^{-1}, SD = 1.19) and the downstream transect (M = 3.27 mgl^{-1}, SD = 1.15), $t(7) = 3.12$, $p < 0.05$, with the reservoir having a significantly higher mean concentration of TSS.

Average values of water conductivity were below the WHO/EU permissible discharge upper limit of 250 µ*S*.cm^{-1}, and were comparable to what was known for unpolluted sites of Lake Victoria whose field data fluctuated between 90 and 130 µ*S*.cm^{-1} (Wanda: unpublished data). There were however, no significant differences in water conductivity between the upstream (M = 100.15 µ*S*.cm^{-1}, SD = 10.64) and downstream (M = 101.89 µ*S*.cm^{-1}, SD = 11.58) transects $t(16)$, $p > 0.05$; between the upstream transect (M = 100.15 µ*S*.cm^{-1}, SD = 10.64) and the reservoir (M = 100.73 µ*S*.cm^{-1}, SD = 4.56), $t(7)$, $p > 0.05$; and between the reservoir (M = 100.73 µ*S*.cm^{-1}, SD = 4.56), and the downstream transect (M = 101.89 µ*S*.cm^{-1}, SD = 11.58), $t(7)$, $p > 0.05$.

Although there was no NEMA/EU/WHO environmental standard for water column clarity, this parameter was comparable to that of Lake Victoria's unpolluted sites (Wanda: unpublished data). Water clarity ranged between 1.3 and 2.4 m at the upstream; 1.3 and 2.5 m at the downstream; and 1.4 and 2.3 m in the reservoir. A significant difference in mean water column clarity was noted between the upstream (M = 1.91 m, SD = 0.33) and downstream (M = 1.79 m, SD = 0.34) transects, $t(17)$, $p < 0.05$, with the upstream having a significantly higher mean value; and between the downstream transect (M = 1.79 m, SD = 0.34) and the reservoir (M = 1.84 m, SD = 0.34), $t(7)$, $p < 0.05$, with the reservoir having a significantly higher water column clarity. However, no significant differences in water column clarity were noted between the upstream transect (M = 1.91 m, SD = 0.33) and the reservoir (M = 1.84 m, SD = .34), $t(7)$, $p = 0.05$. Throughout the sampling period, the mean concentrations of oil and grease were below the permissible NEMA upper limit of 10 mgl^{-1} and ranged between 0.0 and 0.60 mgl^{-1} at the upstream transect; 0.0 and 0.90 mgl^{-1} at the downstream transect; and 0.08 and 0.23 mgl^{-1} in the reservoir (Figure 6). The concentration of oil and grease was however, significantly different between the upstream (M = 0.13 mgl^{-1}, SD = 0.01) and the downstream (M = .24 mgl^{-1}, SD = .06), $t(16)$, $p < 0.05$; and between the upstream transect (M = 13 mgl^{-1}, SD = .01) and the reservoir (M = .18 mgl^{-1}, SD = 0.05), $t(7)$, $p < 0.05$. Oil and grease concentration was however, not significantly different between the upstream transect (M = 0.13 mgl^{-1}, SD = 0.01) and the reservoir (M = 0.18 mgl^{-1}, SD = 0.05), $t(7)$, $p > 0.05$.

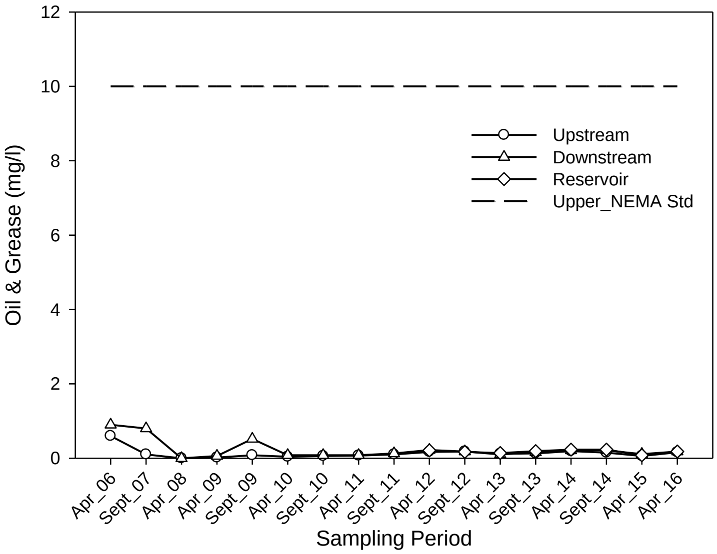

Figure 6: Trends in concentration of oil and grease compared to NEMA permissible upper limit

Discussion

Reservoirs, like lakes, are created when water storage projects are built. Dams and their reservoirs can as such significantly slow down the rate at which the water flows downstream (Ligon *et al.*, 1995; Kondolf, 1997; Nilsson *et al.*, 2005). When the Bujagali reservoir was established, riparian areas became inundated, habitat conditions changed and over time, this probably resulted into a new equilibrium of the reservoir (Soares *et al.*, 2008).

During the first years after a reservoir is filled, the decomposition of submerged vegetation and soil organic matter can drastically deplete the level of oxygen in the water (Tank *et al.*, 2010; Zhu *et al.*, 2011). Reservoirs often "mature" within a decade or so, although in the tropics, it may take many decades or even centuries for most of the organic matter to decompose (Hamilton and Schladow, 1997; Soares *et al.*, 2008). Since much of the site was steep-sloped, the amount of submerged macrophytes was limited to the few sheltered bays hence their contribution to the organic matter load in the inundated area was assumed to be minimal. When algae in a reservoir senescence and die, they sink to the hypolimnion, where they decay and in doing so, consume the already limited hypolimnetic oxygen (Nürnberg, 2004). However, presence of adequate concentrations of dissolved oxygen in a river is one of the main indicators of good water quality (Best *et al.*, 2007; Carsten *et al.*, 2007). Water low in dissolved oxygen can "suffocate" some aquatic organisms and make such water unfit for various uses including human consumption. Dissolved oxygen is also vital for bacteria-mediated break down of organic detritus and pollution (Young *et al.*, 2008). At all sites, dissolved oxygen was above the lower NEMA and EU permissible limits of 3 and 5 mg L^{-1}, respectively, a situation that rendered the project area suitable for supporting low oxygen intolerant aquatic life including most fish species. Before April 2012 when the reservoir was not filled, the flow-through of the water was reflected in terms of the relatively high but similar concentration of dissolved oxygen at the upstream and downstream transects. However, after filling the reservoir, the concentration of dissolved oxygen reduced in similar proportions, but with the downstream transect having a significantly high concentration. The significantly higher dissolved oxygen at the downstream transect was attributed to the enhanced residence time of 16 hours that probably allowed ample time for algae, through photosynthesis, to yield more oxygen such that by the time the reservoir water was released, there was relatively high concentration of the dissolved oxygen. Additionally, decomposition of organic matter results into accumulation of gases such as carbon dioxide which, in aqueous states, lower pH of the water. Despite this, water pH fluctuated within the permissible NEMA and EU/WHO environmental limits of 6 to 8, and 6.5 to 8.5, respectively. This relatively constant pH, coupled with the short residence time of 16 hours, indicated no extreme effects of the project on the pH of the upper Victoria Nile water.

Water temperature has a major effect on the metabolic rates and physiological responses of aquatic biota and on the rates of chemical, biochemical and biogeochemical reactions in a reservoir (Dallas, 2008). The trend in water temperature indicated minimal variations before and after the dam was completed. However, the relatively low water temperature at the upstream transect was partly attributed to the slightly low concentration of TSS that likely trapped less solar energy compared to what was noted in the reservoir. Since there is a strong correlation between TSS and turbidity (Packman *et al.*, 1999; Paaijmans *et al.*, 2008; Hui *et al.*, 2011), turbid waters tend to absorb more solar energy than clear water. The differences in water temperature, though insignificant, were therefore partly attributed to differences in the concentration of TSS. Additionally, water turbidity affects water temperature as suspended particles in a water column absorb and scatter sunlight and hence determine the extinction of solar radiation (Paaijmans *et al.*, 2008). This also had a bearing on the significantly high water clarity at the upstream transect compared to that at the downstream transect. Surface waters tend to become warmer as the slack water absorbs more heat from the sun. Warming or cooling the natural river affects the amount of dissolved oxygen and suspended solids it contains, and influences the biogeochemical reactions which take place in it.

While there were no significant differences in the concentration of TSS between the upstream and downstream transects, and between the upstream transect and the reservoir, the significant difference in TSS concentration between the downstream transect and the reservoir, with the reservoir having a significantly higher concentration was a result of release of accumulated TSS from the latter. However, the significantly low concentration of TSS before and after completion of the dam compared to the NEMA permissible environmental upper limit of 100 mgl^{-1} was an indicator that the project had so far had no significant negative effect on the water environment of this area in relation to TSS.

Water conductance quantitatively reflects the status of inorganic pollution and is a measure of total dissolved solids and ionized species in waters (Jonnalagadda and Mhere, 2001). Although it was anticipated that the submerged vegetation and soil organic matter would decompose and products of decomposition alter water conductivity, this parameter varied minimally at all sites. While there was no NEMA environmental standard for water conductivity, reference to the WHO/EU environmental discharge standard indicated that water in the project area was not significantly affected by the project since even the highest recorded water conductivity was less than half of the upper WHO/EU permissible environmental standard of 250 $\mu S\ cm^{-1}$. While this was so for water conductivity, the significantly low water column clarity at the downstream transect was a result of release of the accumulated TSS from the reservoir. Despite the observed trends in water column clarity, mean values were not very different from what was recorded for unpolluted sites of Lake Victoria (Wanda, unpublished data). Additionally, the concentrations of oil and grease were far below the permissible environmental discharge standard of 10 mgl^{-1}, a situation that indicated that the project did not have negative significant effects on the concentration of oil and grease in the upper Victoria Nile water.

While the above observations indicated no significant impacts of the BEL project on the major water physico-chemical characteristics, elsewhere other scholars have documented alterations by similar projects on water physico-chemical characteristics that profoundly affect the ecology of river systems (Goodwin *et al.*, 2006; Horlacher *et al.*, 2012). Moreover, Berkun (2010) reaffirmed that urbanization and industrialization that are fueled by the relatively affordable hydropower, result into social and economic development, but bring about increased pollution levels that degrade water quality. Thus, water quality is not only impaired by hydropower projects but also by other factors such as urbanization and industrialization, among others. The effect of seasonality was not realized because data collection was done in April and September which are in the bracket of the long (February to May) and short (August to October) rains, respectively. Thus, lack of the dry season data which could be compared with that of wet season, could have influenced the trends that were observed during this study.

This study has demonstrated that more than ten years since the project was initiated, there has so far been no significant negative effect of the BEL project on the major water physico-chemical parameters of the upper Victoria Nile water. This was probably due to the short residence time of 16 hours which was probably not long enough to impact on the various physico-chemical changes of the water. Additionally, since data collection was done only during the rainy seasons (April and September), the effect of seasonality could not be realized due to lack of comparable data if sampling was also done during the dry season.

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