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Potential Impacts of Oil and Grease on Algae, Invertebrates and Fish in the Bujagali Hydropower Project Area

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Abstract. This study determined the concentration of oil and grease and inferred its impacts on algae, invertebrates and fish. Water samples were collected in April and September from 2012 to 2018 at the upstream and downstream transects and in the reservoir, and analysed for oil and grease following standard procedures. Environmental compliance was compared to NEMA's discharge standard of 10 mg/l, and its PAH effluent discharge standard of $\leq$ 0.1 mg/l. At all sites, average concentrations of oil and grease were below 10 mg/l throughout the sampling period. Out of the 14 data sets for each transect, only 3 along the upstream transect, and 2 at each of the downstream transect and the reservoir were compliant with the effluent discharge standard. Although impacts of oil and grease on aquatic biota were not assessed, their relatively high concentration compared to total Polycyclic Aromatic Hydrocarbon (> 0.1 µg/l) is considered hazardous to most aquatic organisms. The diverse activities around the project area implied that sources of oil and grease were proportionately diverse. Hence, the observed trends may not solely be attributed to the hydropower project. Accordingly, assessment of the various sources of oil and grease and their impact on aquatic biota in the area is recommended.

Keywords: Water quality, Pollution, Algae, Fish.

Introduction

About 3.5 million tons of petroleum hydrocarbons enter the aquatic environment annually, either directly or indirectly from anthropogenic and natural sources (Maletić *et al.*, 2019). While effects of oil and grease contamination on the aquatic ecosystems may not be significant on a global scale, local catastrophes may occur, and in areas affected by oil leaks, local populations of invertebrates, birds and mammals may be greatly reduced and aquatic saprophytes may die off (Maletić *et al.*, 2019). The concentration of dispersed oil and grease is an important parameter for water quality and safety (Osibanjo *et al.*, 2011; Westerhoff *et al.*, 2018). Oil and grease includes fats, oils, waxes, and other related constituents found in water and wastewater (Achanta *et al.*, 2011; Lugt and Pallister, 2012; Radulescu *et al.*, 2018), and their low solubility reduces their rate of microbial degradation (Bai *et al.*, 2011). The petroleum industry has grown at a fast rate since its inception and became an indispensable element of most communities and has led to generation of waste products. As such, proper management of waste oil is necessary to prevent its adverse impacts on the environment. Kerosene, in addition to lubricating and road oils are derived from petroleum and coal tar, and contain essentially carbon and hydrogen (Rodgers and McKenna, 2011), while the fate of organic oil and fat from restaurants and other commercial kitchens is probably one of the most forgotten, yet presents critical issues in waste management, especially in developing countries (Stoll and Gupta, 1997), Uganda inclusive. Fats and oils are regularly used in the preparation of food, but residual cooking oil, margarine and butter often end up being washed down the kitchen sinks into drainage systems. The items that are flushed down sinks and toilets can block pipes and cause pollution. These fats and oils collect inside the sewers and over time, harden to a concrete-like material and restrict the flow of wastewater in the pipes (Dominic *et al.*, 2013; He *et al.*, 2011). These blockages can cause wastewater to exhibit a back flow through toilets and sinks into homes and business centres, or escape through manholes into streets and rivers. Blockages from oil and grease or from unsuitable items being flushed away can have a harmful effect on the environment and may lead to pollution in surface water systems like streams, rivers and lakes (Madanhire *et al.*, 2016; Chand and Kumar, 2017). Oil and grease in water can cause surface films and shoreline deposits, leading to environmental degradation, and can induce human health risks when discharged in surface or ground water (Pisal, 2010). Additionally, they may interfere with aerobic and anaerobic biological processes and lead to decreased wastewater treatment efficiency.

The BEL project area has an extensive hinterland composed of terrestrial, aquatic and aerial compartments with several activities that can generate and discharge unknown quantities of oil and grease, and other related pollutants. These activities include several vehicle repair garages and washing bays, in addition to storage facilities for processed oil reserves and car parking lots. Other activities include those associated with food kiosks, restaurants and hotels, the Kimaka airstrip, and the various categories of motorized marine vessels that ply Lake Victoria. Without proper planning to handle pollution arising from oil and grease discharges, the general landscape is at risk of being polluted. Therefore, resources including the quality of surface water for domestic and industrial use, and fish for human consumption are at risk of being contaminated. This study therefore aimed at collecting baseline and subsequent data on the status of oil and grease to determine whether water of the upper Victoria Nile was affected by the BEL project and whether this water was safe for sustaining some aquatic biota notably algae, invertebrates, fish, birds and mammals. Literature information was used to establish whether the water of the project area met Uganda's National Environment Management Authority's (NEMA's) organic effluent discharge standards (Statutory Instruments Supplement No. 44, 2020).

Materials and Methods

The Bujagali Energy Limited (BEL) hydro power dam was constructed on the section of the Victoria Nile that lies between the upstream transect (Kalange-Makwanzi, ~ 2.5 km from the reservoir) and the downstream transect (Buyala-Kikubamutwe, ~ 4 km from the reservoir) (Figure 1).

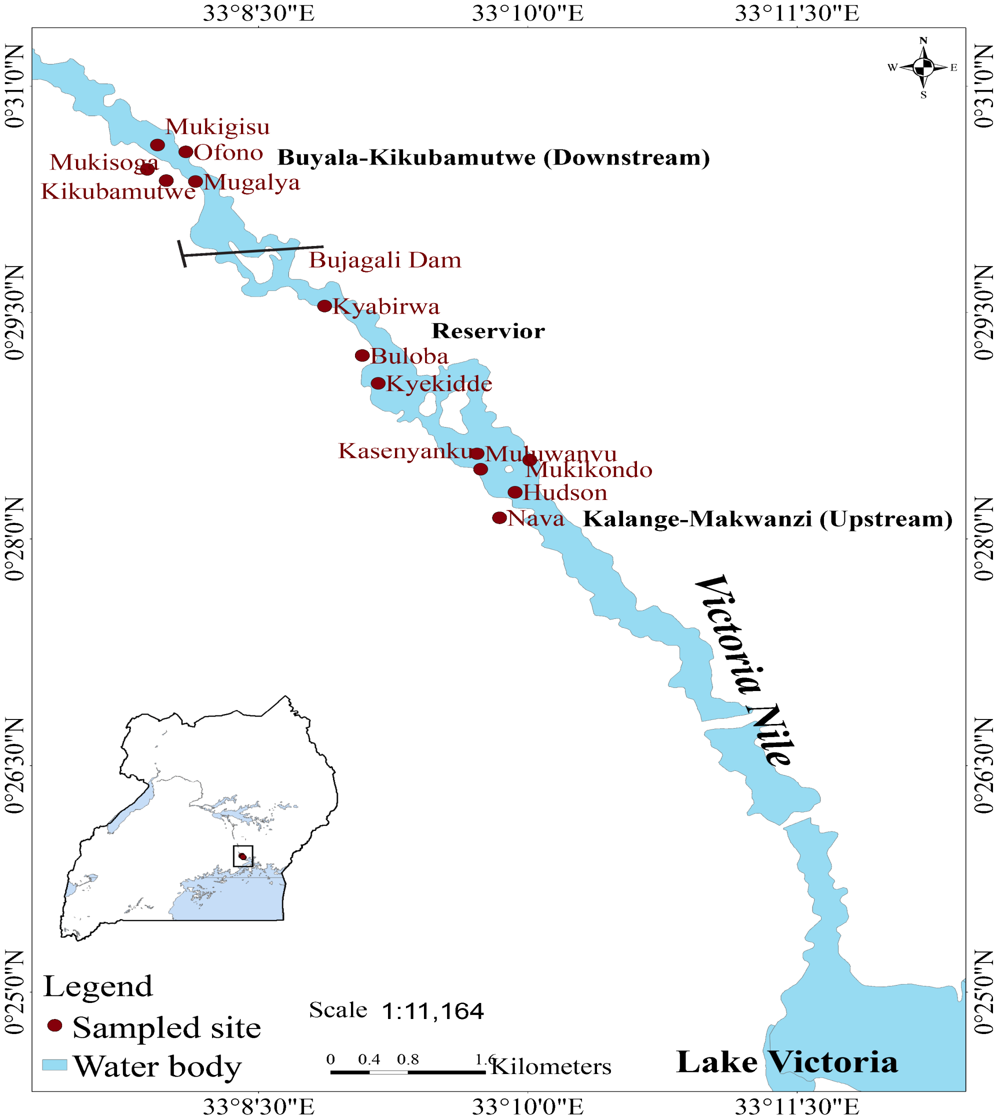

Figure 1: Location of Bujagali Hydropower Project.

This section of the Victoria Nile was characterized by strong waterfalls, rapids, rocky outcrops and river bends. The hinterland along the banks of the river (i.e. 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 covered the river banks and islands. Similarly, in the more northerly downstream sections (~ 4 km from the reservoir), the river banks had been transformed into sparse human settlements and small holder farmer fields (Bassa et al., 2019).

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 was comparatively small as the reservoir water was contained within the steeply incised banks of the river. The reservoir had a maximum depth of 30 m and a mean depth of 9.3 m. Water in the reservoir had a residence time of 16 hours and the reservoir's daily fluctuation was between 2.0 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 field sampling to the months of April and September of each subsequent year. Thus, water samples to generate data on the concentration of oil and grease were collected biannually from 2012 to 2018 during the months of April and September from the upstream and downstream transects, and in the reservoir (Fig1). For each transect, there were 126 samples i.e. 2 months per year x 7 years of sampling x 3 sites along each transect x 3 (triplicates) (i.e. 2x7x3x3). Integrated water samples were collected 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 mls of each sample was put in glass bottles and preserved using a few drops of hydrochloric acid and kept on ice in a cool box. Preserved water samples were analysed the same day for oil and grease using the partio-gravimetric method as described in Greenberg *et al.* (1992). Statistical analysis was done using IBM SPSS Version 20 to compare NEMA's effluent discharge standard with means of oil and grease concentrations at the three transects using Paired Samples T-Test at $p=.05$. Although the concentration of Polycyclic Aromatic Hydrocarbons (PAHs) were not analysed, they were assumed to constitute 10% the concentration of oil and grease (Khaustov and Redina, 2017; Morales-Caselles *et al.*, 2017; Statutory Instruments Supplement No. 44, 2020). The PAH in the water samples could not be determined directly because of lack of laboratory analytical infrastructure for its analysis. Although studies on impacts of oil and grease on water quality and on aquatic biota (i.e. fish, shell fish, phytoplankton, zooplankton, mammals and birds) were not undertaken in the BEL project area, inferences were made based on literature information.

Results

While the BEL hydro power project was initiated in 2006, data on oil and grease is reported from April 2012 because this is when the reservoir was filled and formed the third transect after the upstream and downstream transects. Average concentration of oil and grease for April and September from 2012 to 2018 plus the NEMA Effluent Discharge Standards for wastewater are presented in Table 1. Out of the 7 data sets from each transect for each year, all had average oil and grease concentrations of < 10 mg/l which is NEMA's permissible Effluent Discharge Standard. However, when compared with PAH's ≤0.1 mg/l which is 10% of 10 mg/l of the permissible effluent discharge standard for oil and grease, April data had 2 out of 7data sets (i.e. 2015 and 2016) for each of the upstream transect and the reservoir, hence were within the permissible range. The downstream transect also had two data sets (i.e. April of both 2013 and 2016) that were in the acceptable range; the rest of the data sets for April were above the acceptable upper limit of 0.1 mg/l (Figure 2a). For September data sets, only that of the upstream transect in 2017 was within the acceptable upper limit of 0.1 mg/l, hence the rest for the downstream transect and the reservoir were above the acceptable upper limit of 0.1 mg/l (Figure 2b). Average concentration of oil and grease in the water column showed both spatial and temporal variations among sites (Figures 2a and b).

Table 1: Average concentration (mg/l) of oil and grease at the three transects (2012 to 2018) compared with NEMA's Effluent Discharge Standards

Transect	Monitoring periods													
	April 2012	Sept. 2012	April 2013	Sept. 2013	April 2014	Sept. 2014	April 2015	Sept. 2015	April 2016	Sept. 2016	April 2017	Sept. 2017	April 2018	Sept. 2018
Upstream	0.17	0.18	0.12	0.13	0.19	0.15	0.06*	0.16	0.01*	0.33	0.48	0.10*	0.30	1.50
Downstream	0.22	0.18	0.10*	0.16	0.21	0.21	0.11	0.18	0.02*	0.13	0.54	1.10	0.20	2.40
Reservoir	0.21	0.17	0.14	0.19	0.23	0.23	0.08*	0.18	0.02*	0.60	0.54	0.70	0.60	0.60
NEMA's effluent discharge standard for Oil & Grease	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
PAH as 10% of Oil & Grease concentration in effluents	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

*Concentrations falls within NEMA's permissible effluent discharge standard of ≤ 0.1 mg/l.

Sept. = September.

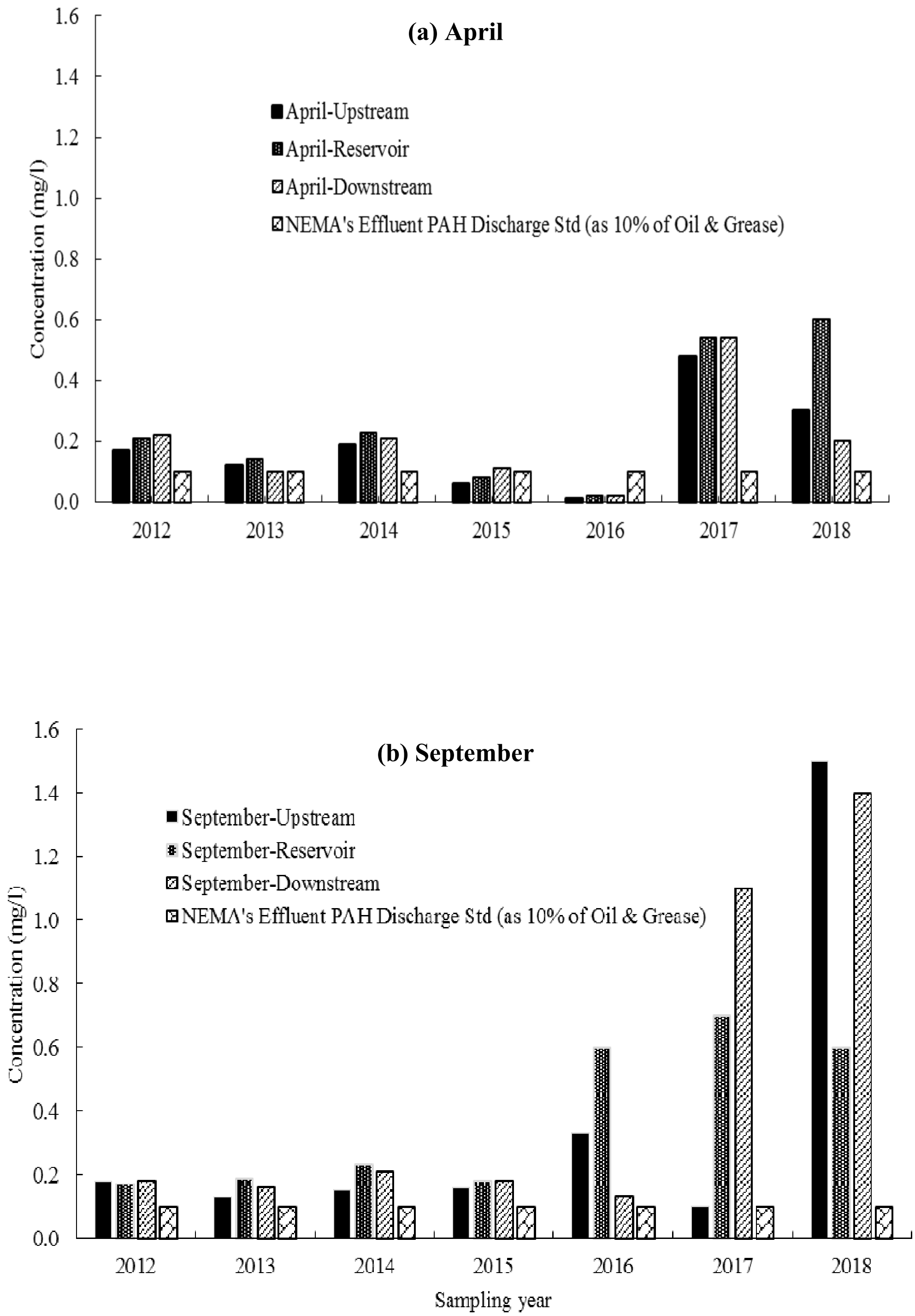

Figure 2. Average concentration of oil and grease at the three transects (2012 to 2018) compared to NEMA's effluent PAH discharge standard

In spite of the noted variations among sites, there were no significant spatial differences in the concentration of oil and grease between the different transects (i.e. Upstream and Reservoir, $p > .05$; Upstream and Downstream, $p > .05$; Reservoir and Downstream, $p > .05$ for April 2012 to 2018; and Upstream and Reservoir, $p > .05$; Upstream and Downstream, $p > .05$; Reservoir and Downstream, $p > .05$ for September 2012 to 2018). Additionally, there were no significant temporal differences in the concentration of oil and grease within each transect between April and September from 2012 to 2018 (i.e. Upstream, $p > .05$; Reservoir, $p > .05$; and Downstream, $p > .05$).

The NEMA effluent discharge standard is such that the concentration of oil and grease should not exceed 10 mg/l in surface water or wastewater. At all the sampling sites along the three transects, the concentration of oil and grease was significantly lower than the NEMA permissible environmental discharge standards. A similar observation was noted for temporal comparison of means with NEMA's Effluent Discharge. From field observations, the likely major sources of oil and grease that end up in the upper Victoria Nile water include storm water from vehicle repair garages and vehicle washing bays in Jinja city.

Discussion, Conclusion and Recommendations

Likely sources of oil and grease in the BEL catchment

The BEL project area, by virtue of its location, is downstream of the major outflow of Lake Victoria, and has a diverse hinterland characterized by several activities on land, on the water and in the air. This implied that whatever activities that resulted into discharge of wastewater contaminated with oil and grease flowing through the BEL facility (i.e. from upstream transect, through the reservoir to the downstream transect) had varying effects on BEL's water quality. Although not evaluated, sources of oil and grease can be as varied as one can imagine, and included discharges from overland flow originating from Jinja city and its surroundings; from the various vehicle repair garages and washing bays; from restaurants and hotels; from the several food kiosks within and around Jinja; and from Kimaka airstrip, among others. Wastewater containing residual cooking fats and oils drained from kitchens in residential places may also add to the oil and grease burden of the receiving surface waters. There could also be accidental oil leaks from marine vessels and light crafts that ply Lake Victoria, and this may significantly contribute to the oil and grease burden, hence may result into some environmental issues of concern.

While the BEL project area forms a transit route for water flowing from Lake Victoria and passing through Nalubaale and Kiira dams that are at the upstream locations of Bujagali Dam, it may not be definite that any oil and grease detected in the BEL project area emanates from the BEL project. Additionally, the various activities within and around Jinja city, which is at the upstream reach of BEL, that may result into discharge of water and wastewater loaded with oil and grease that ends up in surface water passing through the BEL project area, presents a challenging situation as to the contribution of the BEL project to oil and grease in the upper Victoria Nile.

Potential impacts

The acceptable polyaromatic hydrocarbon (PAH) concentration, a major component of oil and grease, is expected not to exceed 0.1 mg/l (Maletić *et al.*, 2019; Khaustov *et al.*, 2017; Statutory Instrument Supplement No. 44, 2020). However, in the upper Victoria Nile water, this standard was in most cases superseded, thus potentially posing a serious concern to the health of aquatic organisms in the upper Victoria Nile water. It is likely that the various sources of oil and grease described above contributed to the oil and grease burden in the upper Victoria Nile. Thus, although not investigated, concentrations of oil and grease with PAH > 0.1 mg/l may have negative effects on aquatic life e.g. when exposed to oil and grease, fish and shell fish may experience reduced growth, enlarged livers, changes in heart and respiration rates, fin erosion, reproduction impairment, and adverse effects on fish eggs and larval survival (McNeill *et al*., 2012; Pilote *et al*., 2018). Additionally, it has been reported that survival of embryos of the Pacific herring (*Clupea pallasii*), was significantly affected by PAHs in a near shore marine habitat of Puget Sound (West *et al*., 2019). Other reports indicated reported that embryos of zebra fish exposed to complex mixtures of PAH from petrogenic sources showed a range of abnormalities including cardiac dysfunction, edema, spinal curvature, and reduction in the size of the jaw and other craniofacial structures (Incardona *et al*., 2004). Further, it was noted that crude oil pollution disrupts cardiac development, morphology and function in embryonic fish. Cardiac impairment was reported to have major consequences on migratory success and fitness in salmon (Alderman *et al*., 2017). Another study revealed that a European sea bass (*Dicentrarchus labrax*) with hypoxia tolerance remained chronically impaired for a minimum of 167 days following an acute 24 hour oil exposure, while the hypoxia sensitive phenotypes did not (Zhang*et al*., 2017). Studies on effects of exposure of Mahi-Mahi fish (*Coryphaena hippurus*) embryos and larvae to oil leaks caused cardiac toxicity during early developmental stages (Xu *et al*., 2016). Similarly, very low embryonic crude oil exposures in pink salmon and Pacific herring in shoreline spawning habitats throughout Prince William Sound in Alaska caused lasting cardiac defects (Incardona *et al*., 2015). Other studies revealed that crude oil disrupts excitation-contraction coupling in fish heart muscle cells, and it was found that salmon and herring embryos exposed to trace levels of crude oil grew into juveniles with abnormal hearts and reduced cardiorespiratory function, the latter a key determinant of individual survival and population recruitment (Incardona *et al*., 2015). Oil spills were also noted to be a potential threat to the recruitment and production of fish, and PAHs, particularly 3-5-ringed alkyl PAH, are components of oil that cause chronic embryo toxicity (Hodson, 2017). Other studies where embryos and larvae of Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) exposed to saturated hydrocarbons, monoaromatic and polyaromatic hydrocarbons (MAHs, PAHs) as well as oxygenated compounds (e.g. phenols, acids and ketones) for a four-day period, were smaller, with signs of cardio toxicity, and jaw and craniofacial deformations (Hansen *et al*., 2019a and b). It was reported that early-life stages (embryos and larvae) of fish are more sensitive to oil exposure than adults (Dupuis and Ucan-Marin, 2015). The fathead minnow fish *(Pimephales promelas*) were found to be more sensitive to Campus Parking Lot Storm water than *Ceriodaphnia dubia*, with decreased survival in 92% and 15% of the samples (n = 13), respectively (McQueen *et al*., 2010).

Abbaspanah *et al*. (2013), who studied *Anabaena* sp. (a blue-green algal species) under controlled conditions, found that its photosynthetic activity decreased with increasing oil concentration. It was further found that chlorophyll *a* and phycobiliprotein contents in this algae species were reduced with accretion of oil concentration, in addition to complete inhibition of nitrogenase activity. Studies of adaptation of *Scenedesmus* sp (a microalgae) to a gradient of continuous petroleum contamination under laboratory conditions revealed that one strain isolated from the crude oil spill area showed undetectable effects, while that from a pristine environment was rapidly destroyed; however, survivors could adapt to low doses of contamination by means of physiological acclimatization (Carrera-Martinez *et al*., 2011). While these observations were made on the two algal types, it is probable that the same may happen with other algal species, including those occurring in the upper Victoria Nile. Additionally, large and extensive oil spills may rapidly inhibit photosynthesis of microalgae (the main primary producers in aquatic ecosystems), causing a severe damage to inland waters and marine ecosystems (López-Rodas *et al.*, 2009).

Inhibition assays were assessed on long-term eco toxicity of storm water samples on mobility of a planktonic crustacean that belongs to the subclass Phyllopoda (i.e. *Daphnia magna*); population growth of a microalga (i.e. *Pseudokirchneriella subcapitata*); growth of a freshwater ostracod (i.e. *Heterocypris incongruens*); and reproduction of one generation of a water flea in the class Branchiopoda (i.e. *Ceriodaphnia dubia*) (Gosset *et al.*, 2018). These scholars however, did not observe any adverse effect on the first exposed generation, but an increase in mortality and a reproduction disturbance was obtained in the second and third exposed generations. The same scholars (Gosset *et al.*, 2018) also undertook a preliminary assessment of long term eco toxicity of urban storm waters using a multigenerational bioassay on *Ceriodaphnia dubia*. This micro crustacean (*C. dubia*) is considered one of the most sensitive, especially regarding reproduction impairment as a toxicity endpoint. It was noted that there were no adverse effects on the first exposed generation, but an increase in mortality and a reproduction disturbance was noted in the second and third exposed generations. In another study, Blumer *et al.* (1970) who investigated effects of hydrocarbon pollution of edible shellfish by an oil spill, demonstrated the presence of the same hydrocarbon pollutant in whole oysters (*Crassostrea virginica*) and in the adductor muscle of the scallop (*Aequipectcn irradians*). Axial development of sea urchin embryos was also impaired by PAHs (Pillai *et al.*, 2003). Gerner *et al.* (2017) also noted alterations in the composition and abundance of invertebrate species in terms of increased physiological sensitivity and a decreased generation time for the average species.

Oil and grease destroys the insulating ability of fur-bearing mammals, such as sea otters and the water repellence of a bird's feathers (Szaro, 1977), thus exposing these creatures to the harsh environmental conditions (Samiullah, 1985). Without the ability to repel water and insulate them from the cold water, aquatic birds and mammals may die from hypothermia (Barron, 2012). Many aquatic birds and other animals also ingest oil when they try to clean themselves, which can poison them. Large oil occurrence on aquatic systems as a result of oil spillage has been at the forefront of public concern due to its impacts on the general environment especially as it negatively affects aquatic fauna and flora e.g. as many as 30,000 birds died after the grounding of the Torrey Canyon at Seven Stones Reef, Great Britain in 1967 (Bourne *et al.*, 1967).

Most of the oil in the environment results from the countless discharges of petroleum and petroleum products occurring during normal usage. Most of these discharges are small enough to go uncatalogued, but their global impact may in the long run be determined by the total amount of oil rather than by the size of the individual spills or leaks. Thus, the overall effect of oil and grease pollution on the aquatic environment in general, and on aquatic biota in particular ought to be examined from two points of view of the sub lethal and indirect effects of chronic exposure to low levels of oil and grease in the environment.

Conclusions

1. At all sites, average concentrations of oil and grease were below 10 mg/l which is NEMA's permissible effluent discharge standard.
2. Out of the 14 data sets for each transect, only 3 along the upstream transect (i.e. April of 2015 and 2016, plus September of 2017), 1 in the reservoir (i.e. April of 2016), and 2 at the downstream transect (i.e. April of 2013 & 2016), were compliant with NEMA's permissible effluent discharge standard for oil and grease.

3. Although impacts of oil and grease plus the associated total Polycyclic Aromatic Hydrocarbons (PAHs) on aquatic biota were not assessed, the relatively high concentration of these PAHs compared to the permissible standard (PAHs ≤ 0.1 μg/l) was considered hazardous to most aquatic organisms in the project area.
4. The diverse landscape around the project area implied that sources of oil and grease were probably proportionately diverse, hence the observed trends may not solely be accounted for by the BEL hydropower project.

Recommendations

Sources of oil and grease ought to be determined and quantified given the divers activities that produce these pollutants within the catchment. Additionally, studies on effects of oil and grease pollution on water quality and associated aquatic biota should be done in order to guide policy recommendations for management.

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