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Full Length Research Paper

Efficiency of the Nakivubo wetland as a filter for heavy metal pollutants of Kampala urban effluent into Lake Victoria, Uganda

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The population of the Ugandan capital city of Kampala has dramatically increased since the political turmoil of the 1970s and with it a considerable rise in industrialisation. Few manufacturing plants, however, have pretreatment installations in place for their polluted effluent prior to discharge into the surrounding ecosystems. Kampala's main drainage system is the Nakivubo channel which empties directly into the neighbouring Lake Victoria, the second largest inland freshwater lake in the world. Increased urban effluent load coupled with reclamation for crop farming have considerably reduced the effectiveness of the wetland to filter out major pollutants, in particular heavy metals. Using atomic absorption spectrophotometry, this study showed that the efficiency in sieving out zinc (Zn), copper (Cu), cadmium (Cd) and lead (Pb) has shrunk from 89.7 – 98.3% in December 2006 to 79.4 – 92.1% in December 2008, over a period of three consecutive years. This is indicative of the growing ineffectiveness of the wetland to absorb heavy metals. Levels of the same metals in the lake water some two kilometres away from the mouth of the wetland have correspondingly increased from 23 - 31% to 35 47% in the same period. This poses a serious threat to the quality of the fish and to the over two million urban population that directly depend on the lake water for domestic and industrial use. The remedy lies in the relevant authorities to enforce pretreatment at each factory site, increased factory management sensitisation on environmental concerns and more stringent measures against wetland encroachment.

Key words: Kampala urban effluent, Nakivubo wetland, heavy metal filtration, Lake Victoria.

INTRODUCTION

Uncontrolled human settlement and industrial development have exerted extreme pressure on the wetland drainage system in Kampala urban district. The Ugandan government strongly encourages private investors and the growth of the industrial sector in an effort to promote value addition to locally produced items and subsequently discourage the export of raw materials on the international trade market. This has resulted in rapid increase in the number of manufacturing industries in the city, with little attention to their attendant effects on the environment. Among these are zinc- and lead-based paint factories, a lead-acid accumulator manufacturing and recycling factory, steel-rolling mills and small-scale metal workshops, an electric cable manufacturing plant and many more. Few of these, however, have pretreatment measures on site but simply discharge untreated effluent directly into drainage tributaries that team up to form the Nakivubo channel. The only pretreatment the effluent load gets before emptying into the lake is the sifting by the wetland. But wetlands have limited capacities beyond which their effectiveness begins to decline. With the rapid expansion of population and industrialisation in the capital city, Uganda is presently faced with mounting untreated polluted effluent entering the neighbouring Murchison Bay of Lake Victoria via the Nakivubo channel wetland, the main drainage system in the urban setting. Lake Victoria is the second largest inland freshwater lake in the world. The Nakivubo channel cuts right across the city (Figure 1) and empties

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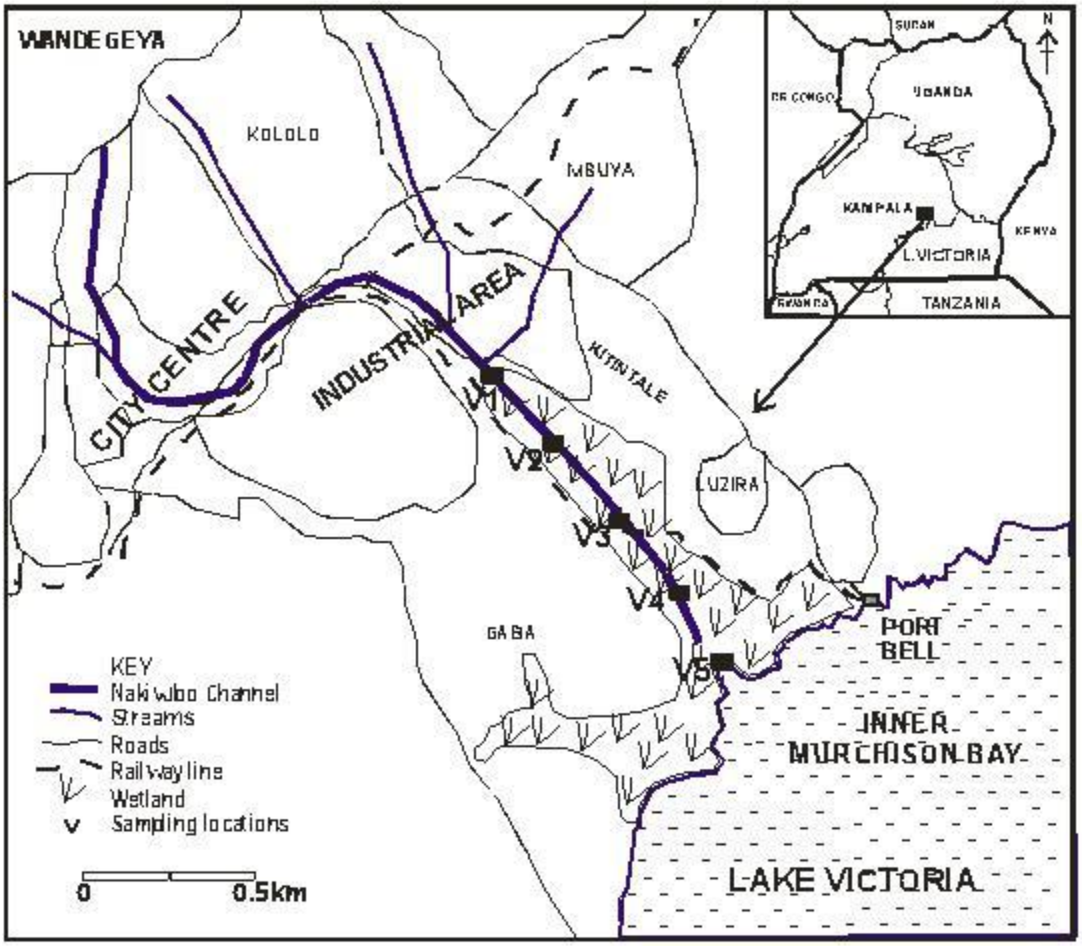

Figure 1. Schematic map of Kampala City, Uganda (East Africa), showing study area.

into a level terminal wetland. A considerable degree of crop cultivation takes place on the wetland by unaware small-holding farmers, growing sugarcane, yams, coco-yams, sweet potatoes and a variety of other vegetables. These crops are used for home consumption and the rest sold to unmindful passer-by city dwellers.

Major pollutants in the effluent are toxic heavy metals. The term heavy metal refers to any metallic chemical element that has a relatively high density and is toxic or poisonous even at low concentrations. Examples of heavy metals include copper, mercury, cadmium, zinc and lead. These may enter the human food chain via the food crops grown on the urban wetland and the freshwater fish from the lake. A lot of fishing activities take place in the waters of the lake, with sizeable daily catches of tilapia and Nile perch (Njiru et al., 2006). Although most of the fish is consumed locally by over two-million urban population (Uganda Bureau of Statistics, 2005), some of it is processed and exported to international markets both on the African continent and overseas. Already there are signs of poisoning of fish in Lake Victoria both from heavy metals (Birungi et al., 2007) and other toxins (Ogwok et al., 2009; Munabi et al., 2009; and Nyakairu et al., 2009). Also, the city draws most of its freshwater for domestic and industrial use from this lake. The urgent need to maintain the ecological balance of this international water body is apparent therein and this can best be achieved by controlling the quality of effluent from the surrounding cities, towns and inland ports on mainland East Africa discharging into the lake.

Studies about the Lake Victoria have shown a gradual increase in the presence of heavy metals in the lake water over the recent years (Onyari and Wandiga, 1989; Kishe and Machiwa, 2002; Mwamburi, 2009). A large percentage of the metals are in the cationic form (Mbabazi et al., 2009), the most toxic form to fish (FAO/WHO, 1993). The cationic heavy metal content is also accentuated by the National Water and Sewerage Corporation (NWSC) Bugolobi Water Stabilisation Ponds (WSPs) which also discharge their effluent into the wetland. The tributary swamps and the main wetland have been largely reclaimed for urban cultivation and are no longer fully effective in filtering the high organic and other content of the sub-channels. A variety of other sources and human activities over time have also resulted in the discharge of considerable quantities of heavy metals in the urban environment. These include small-scale metal works, careless dumping of dead lead-acid accumulators, old and rusty galvanized roofing iron sheets, paints (both zinc- and lead-based) and varnishes, aerial factory emissions and leaded-fuel car exhaust fumes notwithstanding. Run-offs from torrential downpours concentrate the pollutants into the Nakivubo channel and eventually into Lake Victoria. Heavy metal ingestion through food chains is injurious to human health. Accumulation of lead in humans is associated with disorders of the nervous system (Sanín, 1998), while cadmium is thought to inhibit the uptake and retention of calcium in bones (Wendelaar-Bonga, and Lock, 2003) Prolonged disposal of bits and choppings of electrical wires contributes to the presence of copper in the urban environment. Copper is extremely toxic and may find its way into the human body through contaminated fish consumption (Arockiadoss et al., 2008).

It is well known that plants exhibit selective absorption for minerals. Filtration of heavy metals by a wetland from the effluent entering it is mainly due to selective absorption by the various plant species in the area. Unabsorbed dissolved heavy metal cations may adsorb onto sediment, form associations with high relative molecular mass (RMM) organic matter or pass on to the lake. Zinc (Cances et al., 2003; Deng et al., 2009), copper, cadmium and lead (Wendelaar-Bonga and Lock, 2003; Deng et al., 2004) are all absorbable by wetland vegetation including any food crops that may be cultivated on the same land (Kachenko and Singh, 2004). Upon decay of the plants the heavy metals may be released back into the wetland system. In the lake the heavy metals may be absorbed by fish via plankton ingestion (Liu et al., 2002) and gills (Weaver et al., 2009). In this way heavy metals enter food chains and may subsequently exhibit toxicological effects in humans (Mugabe et al., 1998; Ssebagala et al., 2004). There is considerable information on the hazards of heavy metal contamination (Järup, 2003). The metals are extremely resistant to changes that would otherwise lead to their partial or complete elimination from the environment. They undergo biogeochemical cycles, their potential toxicity being largely controlled by their physico-chemical modifications. They have a tendency to accumulate in vital human organs (Godt et al., 2006; Chen et al., 2006; Cerovic et al., 2007) such as the brain, kidney, liver, intestinal tract and lungs. They may cause structural damage and/or cell malfunctioning, owing to their interaction with nucleic acids. Heavy metal toxicity may also adversely affect the genetic carrier code via nucleic acid–chelate formation (Sirover and Loeb, 1976; Moreira and Moreira, 2004). The Uganda National Environment Management Authority (NEMA) under Ugandan law (NEMA, 2004a), has put in place statutory instruments (S.I.) for the proper management of national wetland drainage systems, contravention of which constitutes an offence. These generally discourage encroachment on wetlands for public, private, agricultural or other purpose and will normally require a wetland resource use permit. S.I.153 - 11 states that (1) "Any person desiring to carry out any activity in a wetland shall make an application," and that (2) "Any person who contravenes this order by the Executive Director commits an offence." S.I.153-12 of the same law requires that "The Executive Director may issue a permit in Form B permitting the use of wetland resources." In spite of this, however, few ordinary inhabitants in Uganda adhere to this directive and go about their daily subsistence agricultural activities on urban and other wetlands unhindered.

It was therefore important to determine to what extent the urban effluent is polluted with heavy metals zinc, copper, cadmium and lead and the effect of passage through Nakivubo wetland on the pollution levels as the effluent finally enters the lake. To achieve this it was necessary to monitor the heavy metal levels over three consecutive annual periods amidst increased volumes of untreated urban effluent and wastewater. This would shed some light on the current efficiency of the wetland as a filter for heavy metal pollutants. The results might prompt the relevant authorities to put some anti-pollution measures in place for better preservation of human health and proper sustainability of the lake, instead of relying on the wetland alone.

MATERIALS AND METHODS

Study area and sampling

The study area was the Nakivubo channel. The vegetative terminal wetland stretch spans a total distance of some 1½ km (~1500 m) measured straight along the main effluent stream, before its mouth eventually joins with the lake water. The periods of sampling were the months of December 2006 through 2008. Sampling was carried out several times during each of these months. In Kampala, these times, compared to other months of the year, were exceptionally wet with frequent torrential runoffs from the city and increased total effluent volumes and leachates, the latter considered desirable conditions for study. Water samples were taken at the point of entry into the wetland and thereafter at every 300 m along the drainage system to the point where the channel and the lake became indistinguishable (Figure 1). This separation was arrived at so as to allow for significant filtration of the heavy metals by the wetland vegetation to take place and given that the total length of the wetland was ~1500 m, to also be able to obtain measurements at a number of such suitable sites along the wetland. Since effluent water relatively free of solid particles flows near the surface thus easing filtration, samples of water were collected at various depths within 50 cm of the surface at 6 different sites (V1 – V6), using 10 L plastic containers. At each site, a number of samples in the range $5 \leq n \leq 10$ were drawn, arising from various depths owing to undulating sediment deposition and the urgent need to minimise filtration times. The containers were cleaned and rinsed several times with the channel water at each site before use. The water was filtered immediately after sampling, transferred to 5 L polythene containers and labelled with permanent stickers. To minimise any possible effects of microbial activity, the filtered samples were transported in ice-cooled boxes and subsequently kept refrigerated at -10^{o}C until analysis, several days after the sampling process. This made a total of 168 samples (Tables 1 and 2) that were analysed over the three-year period. The site where the combined

Table 1. Total heavy metal levels in urban effluent at various points along Nakivubo wetland, Kampala, Uganda.

Sampling site		Concentration (µg ml^{-1})			
		Zn	Cu	Cd	Pb
December 2006					
V1 0 m, Entry	(*n* = 10)	26.001 ± 0.008	43.667 ± 0.009	7.002 ± 0.004	12.340 ± 0.006
V2 300 m	(*n* = 8)	4.973 ± 0.005	5.538 ± 0.004	0.623 ± 0.004	5.084 ± 0.007
V3 600 m	(*n* = 6)	3.164 ± 0.006	3.159 ± 0.006	0.324 ± 0.005	3.284 ± 0.005
V4 900 m	(*n* = 5)	2.209 ± 0.006	2.238 ± 0.008	0.219 ± 0.004	2.343 ± 0.007
V5 1200 m	(*n* = 7)	1.723 ± 0.007	1.580 ± 0.006	0.172 ± 0.003	1.805 ± 0.005
V6 1500 m Exit	(*n* = 10)	1.378 ± 0.006	1.179 ± 0.005	0.119 ± 0.004	1.271 ± 0.005
December 2007					
V1 0 m, Entry	(*n* = 10)	28.183 ± 0.009	45.296 ± 0.006	7.840 ± 0.005	14.759 ± 0.006
V2 300 m	(*n* = 8)	8.951 ± 0.007	7.730 ± 0.007	1.344 ± 0.004	6.933 ± 0.005
V3 600 m	(*n* = 6)	5.709 ± 0.006	4.924 ± 0.004	0.799 ± 0.004	4.260 ± 0.006
V4 900 m	(*n* = 5)	4.384 ± 0.005	3.658 ± 0.007	0.618 ± 0.003	3.313 ± 0.005
V5 1200 m	(*n* = 7)	3.462 ± 0.006	2.970 ± 0.008	0.552 ± 0.004	2.524 ± 0.004
V6 1500 m Exit	(*n* = 10)	3.015 ± 0.007	2.356 ± 0.004	0.455 ± 0.005	1.889 ± 0.004
December 2008					
V1 0 m, Entry	(*n* = 10)	31.021 ± 0.006	46.941 ± 0.007	8.454 ± 0.004	16.034 ± 0.006
V2 300 m	(*n* = 8)	15.053 ± 0.005	9.620 ± 0.006	1.935 ± 0.003	9.101 ± 0.005
V3 600 m	(*n* = 6)	10.269 ± 0.007	6.738 ± 0.007	1.494 ± 0.004	5.903 ± 0.004
V4 900 m	(*n* = 5)	8.024 ± 0.005	5.069 ± 0.007	1.162 ± 0.005	4.349 ± 0.005
V5 1200 m	(*n* = 7)	6.548 ± 0.004	4.216 ± 0.004	0.941 ± 0.004	3.314 ± 0.004
V6 1500 m Exit	(*n* = 10)	5.611 ± 0.006	3.708 ± 0.005	0.719 ± 0.003	3.303 ± 0.005

Table 2. Total heavy metal levels in Lake Victoria water at Nakivubo channel 2 km offshore.

Period	Concentration (µg ml^{-1})			
	Zn	Cu	Cd	Pb
December 2006, (*n* = 10)	1.354 ± 0.063	1.053 ± 0.018	0.081 ± 0.003	1.154 ± 0.043
December 2007, (*n* = 10)	1.705 ± 0.017	1.155 ± 0.009	0.109 ± 0.005	1.420 ± 0.032
December 2008, (*n* = 10)	1.956 ± 0.009	1.189 ± 0.012	0.166 ± 0.004	1.864 ± 0.009

untreated urban effluent entered the wetland vegetation was for convenience assigned zero distance (Site V1, Figure 1) to act as our point of reference. Also, to serve as our control, relatively un-disturbed composite lake water was reached and sampled by boat, some 2 km offshore at a depth of one metre below the surface.

Analytical procedures

In the laboratory at the time of analysis, 1 L of the water samples from each site was evaporated to dryness. Concentrated nitric acid (10 ml), perchloric acid (2 ml) and hydrofluoric acid (4 ml) were consecutively added to the residue. The mixture was then reheated to dryness, the final residue reconstituted in 2 ml of 2 M hydrochloric acid, transferred to a 25 ml volumetric flask and made up to the mark with distilled, deionised water. The solution was then analysed for the total heavy metallic species concentration using an atomic absorption spectrophotometer (Perkin-Elmer, Model 2380). All the chemicals named and used in this study, including the deionised water, were supplied by British Drug Houses (BDH) and were of analytical reagent (AnalaR) grade, that is, of highest purity.

RESULTS AND DISCUSSION

The total heavy metal levels at various sites along the Nakivubo wetland during the period of study are shown in Table 1. Similar analyses for the heavy metals in the lake water at the same period of time were also carried out and are displayed in Table 2. The WHO maximum permissible levels of Cu, Pb, Zn and Cd (in µg ml^{-1}) in drinking water are: Cu = 2; Pb = 0.01; Zn = 3; Cd = 0.003 (WHO, 2008). The corresponding limits (in µg ml^{-1}) for the heavy metals, according to the Uganda environment management statutes (NEMA, 2004b), are respectively, Cu, 1; Pb, 0.1; Zn, 5; and Cd, 0.1. The results of this study revealed that whereas Zn (1.354 µg ml^{-1}) and Cu

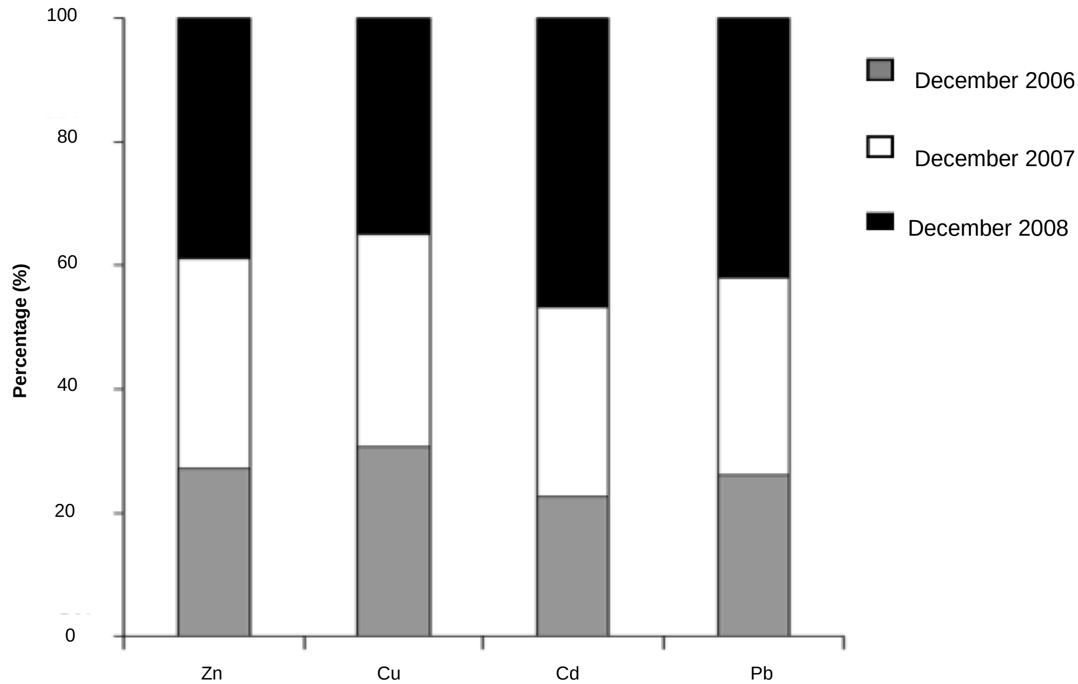

Figure 2. Relative heavy metal levels (%) in water on the Uganda side of Lake Victoria.

(1.053 µg ml^{-1}) levels (Table 2), although undesirable, were still within the permissible limits, while those of Cd (0.081 µg ml^{-1}) and Pb (1.154 µg ml^{-1}) were in the higher range. It is also worthy of note that no such heavy metals were detected, using the methods at our disposal, in the bottled mineral water popularly consumed in Kampala city. Recent speciation studies have indicated that the predominant form of the heavy metals in the lake water (Mbabazi et al., 2009) are the cationic species (80 – 83%), other lesser modifications being anionic and non-ionic, dialysable and non-dialysable. The latter forms were attributed to metals associated with high Relative Molecular Mass (RMM) organic matter. In the lake water itself, most studies have shown that it is the free hydrated form of the heavy metals that is most toxic to fish (FAO/WHO, 1993), that is, Zn^{2+}(*aq*), Cu^{2+}(*aq*), Cd^{2+}(*aq*), Pb^{2+}(*aq*) and the like.

The relative magnitudes on a linear percentage scale of the heavy metal levels in the lake water over the three consecutive annual periods are shown in Figure 2. The results indicated that the total heavy metal content in the lake was slowly but surely increasing. This was attributable to a number of factors, notable among which were the increased industrialisation and wastewater output in the city. That this was so, was accentuated by similar plots, Figure 3, of the levels of heavy metal pollutants entering the Nakivubo wetland from the urban establishment, relative to those in the surrounding lake water at the same period of time. It would seem that the relative purification process varied, not linearly as one would at first expect, but rather asymptotically with distance along the wetland; it is thought that this would be even more so if the vegetation surface density was uniform. This has been interrupted in patches by reclamation. In general the heavy metal content in the untreated effluent was on a gradual increase, while at the same time the absorption *A* which was equivalent to the efficiency *E*, computed as:

$$E = \{1 - (\text{conc. exit/conc. entry}) \times 100\%\}$$

of the wetland to function as a filter of the same metals was on the decline, Table 3. The numerical values of the obtained efficiencies were not constant but rather varied for each year and for each metal, presumably owing to different absorptivities of the metals by the various plant species in the partially reclaimed wetland.

The rise in the zinc content in the untreated effluent entering the wetland showed a significant increase (26.00 – 31.02 µ g ml^{-1}) over the three-year period, Table 1. Whereas zinc is a naturally occurring metal and was expected to be present in low levels in a large water body such as Lake Victoria, its notable presence in urban untreated runoff and effluent was most probably due to two major factors. This is perhaps not too surprising considering that for over a century the major roofing material in the Ugandan capital Kampala has been and continues to be, galvanized iron. Corrosion of such zinc-coated corrugated iron releases considerable amounts of zinc as its oxide or sulphide into the soil and the associated

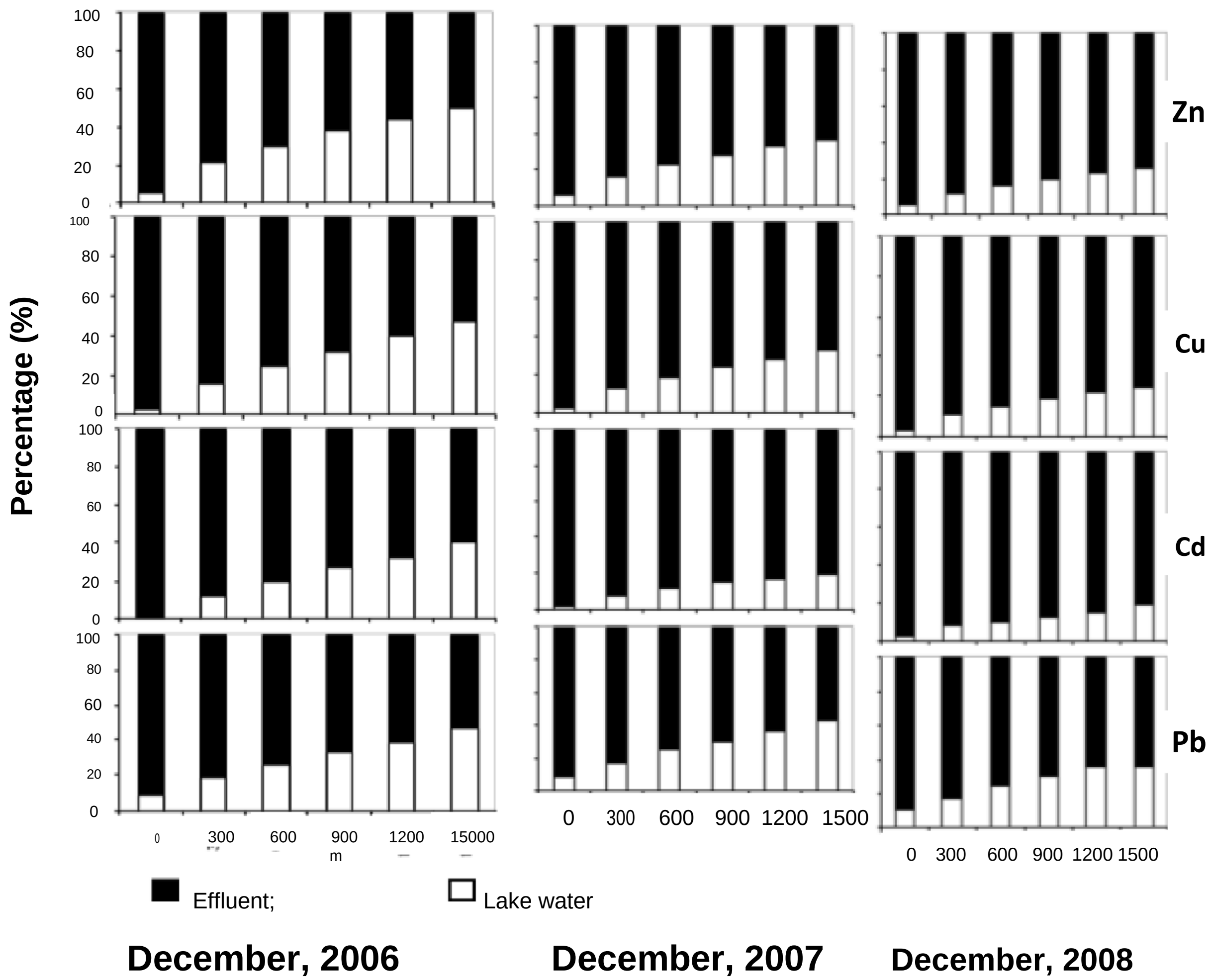

Figure 3. Relative heavy metal levels (%) of urban effluent at various points along Nakivubo wetland.

Table 3. Percentage absorption of heavy metals from urban effluent by Nakivubo wetland, Kampala, Uganda.

Period	Zn	Cu	Cd	Pb
December 2006 (*n* = 10)	94.7 ± 0.4	97.3± 0.4	98.3± 2.9	89.7± 0.4
December 2007 (*n* = 10)	89.3 ± 0.2	94.8± 0.2	94.2± 1.0	87.2± 0.2
December 2008 (*n* = 10)	81.9 ± 0.1	92.1± 0.1	91.5± 0.4	79.4± 0.1

associated drainage channels, the leaching of which concentrates the metal in the wetland water catchment area. The rest is washed down as city runoff during the equatorial downpours. It is possible that the zinc oxides and sulphides subsequently dissolve in the various corro-dents in urban effluent and release the heavy metal mainly in its cationic form. There is a growing shift, however, to the use of fired clay roofing tiles particularly for suburban residential housing. Furthermore, the building con-struction industry has tremendously increased in the city due to growing industrialisation and an even greater an even greater demand for housing and accommodation.

This has precipitated an excessive demand and availability for wall and roof paints, most of which are zinc-based. New paint manufacturing industries have sprung up in the city's busy industrial area (Figure 1). The overall result of these activities is an increased release of zinc metal into the urban environment, which finds its way into the city's major drainage system and if only partially filtered, ultimately into the lake.

Copper on the other hand has exhibited only a slight increase in the lake water over this period, Table 2. The elevated copper content in the water on the Ugandan side of Lake Victoria probably stemmed in the first place from the period of copper smelting at Jinja, which let in a lot of untreated effluent into the lake. The presence of a copper-smelting plant at Jinja for the copper ore from the Kilembe mines in Western Uganda in the 1960s may be blamed for the relatively significant levels of copper in the surrounding lake waters. The plant was located at Jinja owing to its proximity to Uganda's chief source of hydroelectric power, the Owen Falls Dam, which was constructed right at the source of the River Nile and commissioned in 1954. The closure of the smelting plant in the mid 1970s owing to fluctuating prices of metallic copper on the world market, coupled with the un-favourable political climate prevailing in the country at the time put an end to the contaminating effluent. However, the increased usage of electrical copper wire and cables in the city leaves on a daily basis a considerable amount of waste metal in the form of bits, choppings and cut-offs. Metallic copper washed down in the city runoffs subsequently dissolves in the fluctuating acidities and alkalinities of the effluent. Also, the use of copper pipes for running water in the city may be a contributory factor which should not be underestimated. Together these factors gave detectable and above normal (43.67 – 46.94 μ g ml^{-1}) levels of copper in the untreated effluent (Table 1), which if only partially absorbed by the wetland vegetation, were partly responsible for maintaining the levels of copper in the lake water at fairly steady, but not declining, values, Figure 2.

The relatively high level of cadmium in the lake waters (0.081 – 0.166 μg ml^{-1}) during this period may be attributed to the activities of steel-rolling mills in the towns surrounding the lake, in particular Jinja, which processes even scrap metal and discharges untreated effluent directly into the lake. Though the levels of cadmium are comparatively lower than those of the other metals investigated (Table 2), they have increased considerably from 7.00 μg ml^{-1} in the urban effluent in 2006 to 8.45 μg ml^{-1} in 2008, as shown in Table 1. This appreciable rise may be traced to the volume of both small and large-scale metal processing industries that has sharply increased owing to increased demand for iron and steel bars needed for the booming building construction in the city and other places countrywide. Uganda does not possess or mine iron ore deposits, neither does it import the ore; so it is relying heavily on scrap metal from old cars, rusty steel doors, windows, corroded roofing iron and occasionally, rail steel girders. Whereas the recycling of scrap metal is a welcome industry in the country and should be encouraged, during the smelting process traces of cadmium embedded in the scrap iron and steel are released in the effluent of the processing plant and out into the environment. Cadmium has been blamed for large-scale poisoning incidents in industrial workplaces, particularly where any ore is being processed or smelted and among welders who have unsuspectingly welded on cadmium-containing alloys or working with silver solders (Wendelaar and Lock, 2003).

The average levels of lead in the lake water have seen a rise from 1.15 μg ml^{-1} in December 2006 to 1.86 μg ml^{-1} two years later (Table 2). These elevated levels of the metal are accounted for by the established habit of car-washing and emptying of dead lead-acid accumulators directly on the banks of the lake. The relative high levels of this toxic metal in the untreated urban effluent (12.34 - 16.03 μg ml^{-1} ;Table 1), may also be attributed to similar activities taking place by car-washers both within the city itself and directly along the streams and sub-channels leading to the wetland. A major car-battery manufacturing plant was constructed near the Nakivubo channel in the industrial area (Figure 1). This plant has been recycling the lead from dead car batteries for a number of years now and discharges untreated effluent into tributaries that eventually join the Nakivubo channel and on to the wetland. From the turn of the century, traffic on Kampala roads has greatly increased, with long traffic jams being a common sight on the busy city streets. In spite of the availability of unleaded fuel in the country, a number of operators and drivers, supposedly environment insensitive, do not insist on it. As a result, most car engines and numerous small electric generators still run on leaded fuel for hours on end, emitting exhaust fumes that form a dark blanket-like cloud that hangs over the city especially late at night and early in the mornings. The slow aerial deposition of particulates from the combustion of leaded fuel from the congested city transport sector is also a parameter to reckon with. Further, torrential downpours wash down the aerial exhaust Pb laden particulates. Lead paints are also still being used for face-lifting buildings in the city. The combined effect of these activities has probably contributed to the rise in the level of this highly toxic heavy metal in the urban effluent and eventually in the surroun-ding lake waters. The Nakivubo channel is nevertheless not the sole inlet bringing in polluted effluent; there are other inland ports and cities around the lake, notably the ports of Kisumu and Mwanza in the republics of neighbouring Kenya and Tanzania, respectively. The Kagera River from the Republic of Rwanda also drains and empties into the lake. These also contribute to the overall present chemical constitution of the lake water.

For each of the metals investigated in this study, the levels at the mouth of the wetland have steadily increased. If for each annual sampling season the wetland were fully effective in filtering out the heavy metals from the effluent, the relative concentrations would to a good approximation be at the 50% level at the 1500 m sites (Figure 3). In other words the heavy metal content of the filtered wetland effluent would be almost identical to that of the lake water. The observation that the urban effluent bars are in each case longer than those of the lake water indicates only partial and incomplete filtration by the wetland. It would seem, from the overall percentage absorption of the metals (which is also equivalent to the efficiency of the wetland), Table 3, that the ability of the wetland vegetation to sift out the metals in December 2008 was in the decreasing order: Cu > Cd > Zn > Pb, whereas the degree of contamination in the untreated effluent just before the wetland (Table 1) decreased in the order: Cu > Zn > Pb > Cd. However, comparisons of this nature would only be meaningful if the different plant species presently in the wetland had similar absorptivities for each metal. Consequently, the order of the metals in the effluent (that is, Cu > Zn > Pb > Cd) at the point of entry into the wetland is not similar to that (that is, Cu > Cd > Zn > Pb) at the mouth of the same wetland. This is assumed to be due to selective absorption by plants. Nevertheless it was important to note that for each heavy metal the percentage absorption levels decreased over the studied period, a clear indication of the growing ineffectiveness of Nakivubo wetland in filtering out heavy metals from untreated Kampala urban effluent prior to discharge into Lake Victoria.

Conclusion

Our results show that the untreated Kampala urban effluent incident on the Nakivubo channel carries relatively high heavy metal pollution which is followed by a gradual decline as it oozes through the wetland. It finally discharges into the lake with still significant heavy metal quantities compared to the average levels in the lake water. This point to the growing ineffectiveness of the wetland to control the heavy metal pollution. The Ugandan capital Kampala relies on the Nakivubo channel for its drainage of wastewater, runoff and industrial or other effluent. The present heavy metal levels in the channel can no longer be effectively filtered out by the only wetland associated with the channel prior to discharge into Lake Victoria. The levels of heavy metals in the lake water itself are on the rise, which poses a big threat to the only reliable source of fresh water for domestic and industrial use. The levels also threaten the aquatic life, in particular the quality of the fish, in the lake. It is therefore imperative upon the relevant urban authorities in central East Africa to take appropriate measures forcing the industries to treat their effluent at the source before release into the environment. In addition, tougher laws should be put in place as a deterrent against urban wetland encroachers.

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