Pollution menacing Lake Victoria: Quantification of point sources around Jinja Town, Uganda

Hannington W Oguttu[1], Fred WB Bugenyi[2], Heinz Leuenberger[3], Markus Wolf[4] and Reinhard Bachofen[5]*

[1]*Fisheries Resources Research Institute, FIRRI, Jinja, PO Box 343, Jinja, Uganda*

[2]*Makerere University, Department of Zoology, PO Box 7062, Kampala, Uganda*

[3]*VNCPC, Institute of Environmental Science and Technology, Hanoi University of Technology, Hanoi, Vietnam*

[4]*University of Applied Sciences Basel, Institute of Environmental Technology, St. Jakobsstr. 84, CH-4132 Muttenz, Switzerland*

[5]*University of Zurich, Institute of Plant Biology, Zollikerstr. 107, CH-8008 Zürich, Switzerland*

Abstract

Lake Victoria is Africa's largest tropical freshwater lake, important as a source of drinking water and as a source of food for the population in the surrounding region. Due to increased human activities in agriculture and industry during the past decades a continuously increasing inflow of agricultural runoff has been observed, and lately there have also been increased discharges of municipal effluents and industrial wastewater into Lake Victoria. This paper summarises the results of a one-year (1997 to 1998) environmental and ecological study of industrial wastewater point sources in the Jinja (Uganda) catchment area. Main industries concern food processing, textile, leather and paper production and metallurgy. One fish- filleting factory showed the highest annual nutrient loads with 0.13 t NO_3-N, 0.20 t NH_4-N and 0.77 t PO_4-P, while another disposed of annual loads that amounted to 0.10 t NH_4-N and 0.49 t PO_4-P. From food-processing industries, the highest annual load of organic matter (COD) discharged to the lake amounted to 36.8 t. A tannery in Jinja released effluent with an extremely high mean concentration of the very toxic chromium^{+6} of 264 mg·ℓ$^{-1}$, which results in an estimated annual load of 2.2 t of Cr^{+6}. Concentrations of nitrogen and phosphorus from fish-filleting industries and chromium^{+6} from the tannery were far above the allowed effluent limits in Uganda, leading to enhanced eutrophication and bioaccumulation of Cr^{+6} in Napoleon Gulf, Lake Victoria.

The study provides information on point sources of effluent derived from Jinja's industrial sector in an effort to force resource users to move towards a more sustainable pattern of environmental management. The most appropriate way to reduce the ongoing eutrophication and pollution of Lake Victoria would be to reduce the releases of nitrogen, phosphorus, organic compounds and chromium into Napoleon Gulf by on-site pretreatment, so that they remain within non-critical levels. Industries must be required to monitor their effluents before these are discharged into Kirinya National Water and Sewerage Corporation oxidation ponds and finally into Kirinya West urban wetlands.

Keywords: industrial pollution, point sources, heavy metals, potential loads, hot spots, Lake Victoria, on-site pretreatment

List of abbreviations

APHA	American Public Health Association
BOD	Biological oxygen demand
COD	Chemical oxygen demand
DO	Dissolved oxygen
LVEMP	Lake Victoria Environmental Management Project
NEMA	National Environment Management Authority
NWSC	National Water and Sewerage Corporation
SRP	Soluble reactive phosphorus
WHO	World Health Organisation

Introduction

Lake Victoria is Africa's largest tropical freshwater lake and provides a critically important source of drinking water and fish for the rapidly growing population living in the surrounding region. The biology and limnology of Lake Victoria have been summarised recently (Bootsma and Hecky, 2003). The rapidly growing urban population with its increasing demand for freshwater resources and the extensive growth of agricultural and industrial activities have given rise to progressively increasing problems related to the environmental state of Lake Victoria (Ntiba et al., 2000). High nutrient inputs during the past 50 years have increased eutrophication levels in the lake, particularly in the regions along the lake shore (Hecky, 1993). Algal biomass has increased 5 times compared to 40 years ago (Mugidde, 1993) and nearly half of the lake bottom waters become anoxic for several months each year (Hecky et al., 1993).

Despite the chemical and biological changes that have been observed in Lake Victoria in the past, few water research studies have been conducted to understand the significance of these changes, or the causes of these changes, or to identify the critical factors to reduce their impacts on the lake's ecology. Regrettably, Lake Victoria is the primary recipient of industrial and municipal waste in this eastern region of Uganda. Within Jinja Municipality with its more than 72 000 inhabitants, wastewater is directed into the Napoleon Gulf of Lake Victoria. The major sources of water pollution are:

- Disposal of domestic and municipal waste including garbage, excreta and liquid household waste
- Diffuse agricultural runoff containing fertilisers, pesticides and herbicides

* To whom all correspondence should be addressed.
☎ +41 44 634 82 80; fax: +41 44 634 82 04;
e-mail: bachofen@botinst.unizh.ch
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- Land degradation practices
- Industrial effluents.

These pollution sources have been evaluated theoretically for Lake Victoria using environmental models based on the quantities of industrial production, land use, natural purification in rivers and wetlands, and atmospheric inputs (Scheren et al., 2000). Nutrients appear to enter the lake primarily through agricultural runoff and atmospheric deposition, while organic matter originates mostly from discharges of domestic and industrial wastes (Lindenschmidt et al., 1998; Scheren et al., 2000). While diffuse pollution loads from land usage have been studied (Lindenschmidt et al., 1998), this study addresses the pollution that enters Lake Victoria from several specific industrial point sources. These can be better evaluated and controlled in comparison to undefined diffuse sources that enter the lake.

Several companies from Jinja's industrial sector discharge large volumes of untreated effluents into the rivers Nile, Walukuba and Kikenyi, as well as into Jinja's urban wetlands and into Lake Victoria. This results in nutrient enrichment, the accumulation of toxic compounds in biomass and sediments (Campell et al., 2003a; b), loss of dissolved oxygen in the water, fish kills and other nuisances. Wetlands are important in many respects: they recharge groundwater aquifers, protect the shore lines from wave action, clean polluted water and act as nutrient traps (Byamukama et al., 2000). They also assist in conserving biodiversity, e.g. by acting as a shelter and nursery area for fish. Furthermore, wetlands have served and still serve the local people as source of food and raw materials for crafts (Denny, 2001).

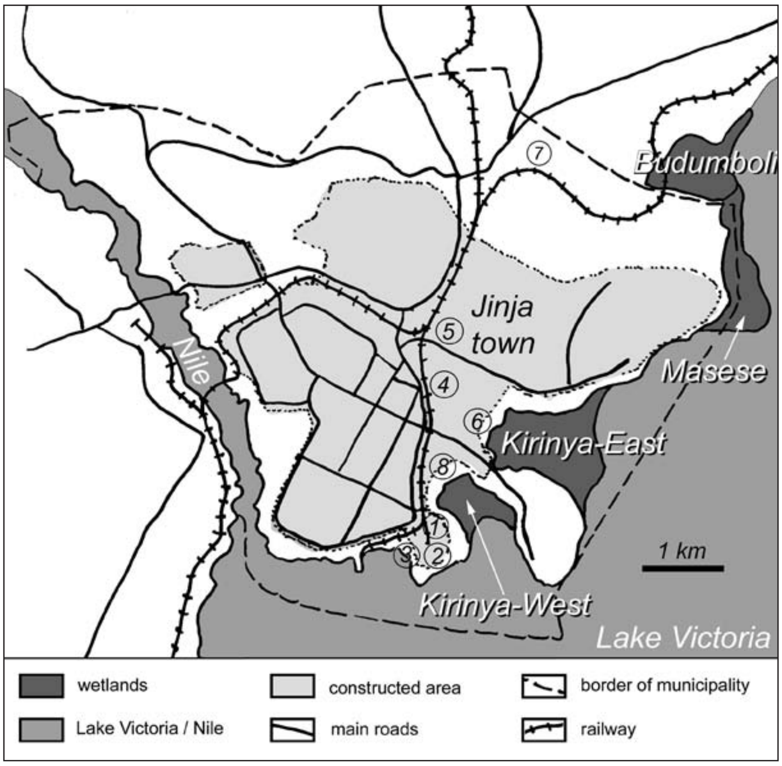

Figure 1
Map of study area: Jinja Municipality with wetlands and location of the industries monitored.
1 Leather Industries of Uganda
2 Agro-Marine Fishing Co. Ltd.
3 Gomba Fishing Co. Ltd.
4 Kengrow (Iganga) Industries Ltd,
5 Uganda Feeds Ltd, Uganda Bread Ltd.
6 Chillington Co. Ltd.
7 Steel Rolling Mills Ltd, Mill Tyres Ltd
8 NWSC Kirinya pond

The Jinja wetland catchment area covers an area of between 42 to 48 km^2 and contains 8 different categories of pollution point sources, including industries that produce or process chemicals, food, fish, tanning of animal skins, textiles, paper and pulp, metallurgy, and beverages. Except for Nile Breweries Ltd., which is located on the western bank of the River Nile and downstream Lake Victoria, the other point sources are all located to the east of the River Nile and along urban wetlands. Their proximity to Lake Victoria is due to the easy access to water that is needed for the many industrial production processes.

Quantitative information on human activities at point sources in the catchment area of Jinja's urban wetlands is urgently needed to identify pollution 'hot spots'. A few water quality data for tropical African inland waters are available from scattered investigations (Saad, 1987; Saad et al., 1990). However, since information on active point sources is lacking for water resource users in Jinja Town, it is difficult to distinguish the effects of point source pollution from those caused by diffuse pollution. Eutrophication of Lake Victoria via polluted water inflows and atmospheric deposition therefore continues to increase in an uncontrolled manner despite the present Ugandan legislation (NEMA, 1995) which requires efficient on-site pretreatment systems for all contaminated effluents in Uganda.

The shoreline of Lake Victoria within the Jinja Municipality boundary is bordered by the Kirinya West/Loco, Kirinya East, Masese and Budumbuli urban wetlands. These wetlands have long acted as filters for nutrients and contaminants that originate from the catchment area, thereby protecting the water quality of Lake Victoria (Kansiime and Nalubega, 2000). However, the shoreline is increasingly influenced by human activities and it is not surprising that wetland degradation has contributed to a gradual change of water quality in Lake Victoria (Verschuren et al., 2002). This can be seen as increased nutrient levels and chlorophyll-*a* concentrations, loss of oxygen in the deeper water, the reduction of biodiversity and an increase in toxic organic compounds over the past decades (Denny, 1988; Hecky, 1993; Hecky et al., 1994; Kansiime et al., 1995; Harro, 1996; Denny, 2001; Verschuren et al., 2002).

This study concentrates on the industrial part of the town of Jinja, especially on the Kirinya West urban wetland which receives most of the domestic, municipal and industrial effluents, surface runoff and stormwater from the town. Each industrial pollutant source was assessed in terms of its location, type of inputs, production processes, economic products, by-products, and harmful effluents. It is hoped that the results will assist these industries and authorities to reach agreement on the need for effluent treatment and then to initiate on-site pretreatment and the adoption of cleaner production technologies at these industrial sites. This will contribute towards more effective multi-sectoral management of industrial effluents within Jinja Municipality and assist in improving water quality in Lake Victoria.

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Materials and methods

Study area

The study area, the industrial centre of Jinja, is located to the east of Jinja Town. Jinja Town is the second largest city in Uganda and is the industrial centre of the country, and is located 80 km east of the capital Kampala. The town is located at an altitude of 1 230 m a.s.l., approximately 45 km north of the equator, and mean daily temperatures range between 17°C and 31°C. Jinja Municipality covers an area of some 28 km^2 and stretches along the northern shores of Lake Victoria (Fig. 1) where the river Nile starts its 6 400 km journey to the Mediterranean Sea. An extensive agricultural landscape surrounds the town, including the large sugarcane plantations of Kakira Sugar Works Ltd. to the north and northwest. Jinja's riparian papyrus wetlands are located to the east of the source of River Nile and along the northern shores of the Napoleon Gulf of Lake Victoria, stretching between 33°10'E to 33°15'E and 0°25'N to 0°30'N. The urban wetlands of Jinja cover areas of 0.5 km^2 (Kirinya West/Loco), 1.0 km^2 (Kirinya East/Walukuba), 0.5 km^2 (Masese) and 0.9 km^2 (Budumbuli), respectively (Koller and Kunz, 1997).

The annual climatic cycle is divided into four seasons - two dry seasons from December to March and from July to September, each of which is followed by a rainy season between March and June and from September to November, respectively. Periods of heavy rainfall coincide with periods with intense evaporation (Jinja Municipality, 1997; Lindenschmidt et al., 1998).

Sampling

Operating factories were assessed in 1997 and 1998 during both the dry season (December 1997 to March 1998) and the rainy season (March 1998 to June 1998). Point sources were selected on the basis of their locations, types of inputs and outputs, availability of on-site wastewater treatment facilities, and the potential environmental impacts of their industrial effluents. Prior to the main sampling campaign, 23 active point sources in the industrial sector of Jinja Municipality (Table 1) were screened in a two-month preliminary survey. Using a random sampling methodology, daily *in situ* measurements were made of DO, pH, conductivity and temperature using calibrated field meters, a WTW oximeter for DO and temperature, a Tetracon 96A-4 meter for conductivity and a WTW pH meter for pH. Two of the companies listed in Table 1, namely Sukari Sugar Ltd and Oxy-Plastic Ltd, were found not to produce wastewater. The National Water and Sewerage Corporation (NWSC) in Jinja, besides supplying drinking water to the local population and industries, also collects industrial wastewater in the Kirinya Pond as a natural wastewater treatment system. Water residence times in this pond are estimated to average 30 d. Input/output data for freshwater and wastewater of the companies that were investigated are listed in Table 4, while their locations are shown in Fig. 1.

This study demonstrated that interviews with industrial workers and management in focus group discussions, using a structured questionnaire entitled 'Assessing the pollution status of the catchment area of Jinja's urban wetlands', were of great importance for collecting data from the industries. Questions posed to each industry concerned qualitative and quantitative information on the goods produced and raw materials used, as well as their by-products, water use, solid waste and wastewater, and wastewater management.

After the preliminary screening, industries were selected on the basis of their effluent flow volumes, presence or absence of on-site pretreatment, importance of the waste as a pollutant, and the relative accessibility of the sampling site for the collection of wastewater samples. Wastewater samples were collected between 9:00 and 23:00 at 30 or 60 min intervals, during 5 periods between November 1997 and June 1998. Besides single samples, time-averaged composite samples were also collected by mixing equal volumes of all samples collected at a single site during 1d. The wastewater samples were kept in polypropylene bottles (cleaned with dilute nitric acid and rinsed with distilled water before use) on ice in coolers at 4 to 6°C, and protected from direct sunlight until analysis in the laboratory. Wastewater discharge volumes were estimated according to Williams (1993).

For analyses of nutrients, the samples were filtered through 0.45 μm membrane filters and the samples were analysed for NO_3-N (Merck Spectroquant Test Kit No. 14773), NH_4-N (Merck Spectroquant Test Kit No. 14752 and *Standard Methods*, 1992), SRP (Merck Spectroquant Test Kit No. 14848 and *Standard Methods*, 1992) within 48 h of collection using standard colorimetric methods with a UVIKON 725 spectrophotometer (Kontron instruments). The COD and the BOD concentrations in wastewater samples were determined from unfiltered samples after appropriate dilution (Merck Spectroquant Test Kit No.

TABLE 1
List of pollution sources of industries in the Jinja catchment area

Type of industry	Companies and industries involved	Wastewater analysed
Tannery	Leather Industries of Uganda	+
Textiles	Textile Mills (Mulco) Ltd. Uganda Garments (Ugil) Ltd.	* -
Beverages	Jubilee Ice & Soda Works Ltd. Garden Tea Ltd.	* -
Fish filleting	Agro-Marine Fishing Co. Ltd. Gomba Fishing Co. Ltd. Masese (Nafco) Fishing Co. Ltd.	+ + *
Food processing except fish	Kengrow (Iganga) Industries Ltd, Kakira Sugar Works Ltd, Sukari Sugar Ltd. Uganda Feeds Ltd, Uganda Bread Ltd. Uganda Millers Ltd, Uganda Grain Milling Co. Ltd.	+ - + -
Pulp and paper	Associated Paper Industries Ltd. Nile Plywood Ltd, Papco Industries Ltd. Timber Investments Ltd, New Printpark (U) Ltd.	- - -
Chemical	Associated Match Co. Ltd. Crown Tiles Ltd, British American Tobacco Ltd. Oxy-Plastics Ltd, March International Ltd.	- - -
Metallurgy	Copper Smelting Co. Ltd. East African Steel Co. Ltd. Chillington Co. Ltd. Steel Rolling Mills Ltd, Mill Tyres Ltd. Uganda Metal Industries Ltd.	* * + + -
Wastewater purification	NWSC Kirinya pond	

All sources were screened for 2 months, then a selection was made based on flow volume, on site pre-treatment, importance of the waste, and accessibility of the wastewater
+ Point sources sampled
** Point sources not active at the time of the project*
- Point sources not sampled

TABLE 2 Characterisation and description of mass flow for selected food processing industries					
Company	**Raw materials**	**Production processes**	**Economic products**	**By-products**	**Hazardous compounds in effluent**
Agro-Marine Ltd.	Fish (30 t·d^{-1} Nile perch, depending on catch), NWSC water (30 - 175 m^3·d^{-1}) , 6% chlorine water, NaOCl & $Al_2(SO_4)_3$, lake water	cleaning, filleting, packaging, shipping (local & international)	Frozen fish fillets, headless gutted fish, head on without gills (6 t·d^{-1}) Ice cubes & flecks	Off-cuts, trimmings, fats, scales, skins, heads, bladders, whole fish rejects	Fresh blood and by-products in wastewater *Note: oxidation pond not operating*
Gomba Fishing Industries Ltd.	Fish (20 - 30 t·d^{-1} average Nile perch) water (minimum 110 m^3·d^{-1}), water for ice plant (20 - 30 m^3·d^{-1}), chlorinated water	cleaning, filleting, packaging, shipping (local & international) Nile perch skin chrome tanning	Frozen fish fillets, fresh or chilled fish fillets, fish meal, dried gall bladders, ice flakes, ice blocks (50 m^3), tanned Nile perch skins, products of Nile perch skins	Off-cuts, trimmings, fats, scales, skins, heads, whole fish rejects	Fresh blood and by-products in wastewater, *Note: Wastewater purification by sand-filtration, aeration, sedimentation* $Cr_2(SO_4)_3$ & CaO from fish-skin tannery
Kengrow Industries Ltd.	Seeds of cotton, sesame, sunflower (10 t·d^{-1}), fatty acids, KOH, dyes, perfumes, palm oil, sodium silicate, NWSC water and borehole water	cleaning, crushing seeds, oil refining, neutralisation, bleaching, filtration, saponification burning seed husks (as fuel)	raw soap (5 t·d^{-1}) Silver Shine blue laundry soap (875 bars day^{-1}). steam, hot water	Cotton seed cake, seed ash & dust Cotton seed husks, as animal food or burned for heat unrefined oil	Thick oily and soapy wastewater, released at night, oil, soap and seed spillage, seed dust, bad odors from stored waste, heat
Uganda Bread Ltd.	Wheat flour (300 kg batch^{-1}), baking fat, yeast, acetic acid, sugar, salt, NWSC water (28 m^3 day^{-1}) boiler oil, liquid detergent	mixing, fermentation oven baking, slicing	family & ordinary bread, scones	damaged & returned bread (250 kg day^{-1}), unfermented dough hot water	unburned bread, oily wastewater, heat
Sukari Sugar Ltd.	Ordinary sugar (local, 9 -10 tonnes day^{-1}), aspartame concentrate (imported) NWSC water (2 -18 m^3 day^{-1})	blending, packaging, selling	Sukari sweet sugar (9 - 10 t·d^{-1})	None (factory in practice operating with clean technology)	none

Data presented were obtained from questionnaires and site visits

14555 and *Standard Methods*, 1992). For metal determinations (copper, nickel, chromium, lead, cadmium and manganese), unfiltered wastewater was digested in concentrated nitric acid (5:1) under reflux for 1 h and, after cooling, filtered through 0.45 µm membrane filters (*Standard Methods*, 1992). Metal determinations were done at the Geology Department, Makerere University, Kampala, by atomic absorption spectrophotometry (AAS)(Perkin-Elmer 2380 AAS). Instrument calibration was obtained with standards of the metals, including internal standards to avoid matrix effects.

Statistical analyses were performed with the statistical package available in Microsoft-Excel.

Results from group discussions, interviews and other information were grouped and the protocols were analysed with regard to effluent inputs, outputs, and processes to supplement the analytical data on the point sources.

Results

Based on the preliminary survey with the parameters temperature, pH, conductivity and DO, the selection of sampling sites was based on:

- Type of industry
- Volume of waste output
- Accessibility
- Daily operation for 12 or 24 h, respectively
- Information from discussions with executives of the company.

TABLE 3 Characterisation and description of mass flow for selected non-food industries					
Com-pany	**Raw materials**	**Production processes**	**Economic products**	**By-products**	**Hazardous compounds in effluents**
Steel Rolling Co. Ltd.	Steel scrap metal (1 000 - 1 500 t·month^{-1}), aluminum scrap metal (40 - 60 t·month^{-1} (local)) Ferro-manganese metal scrap (10 t·month^{-1}), Ferro-silicon metal scrap (10 t·month^{-1} (imported)) NWSC water (20 m^3·d^{-1}), cooling water is recycled, electricity	melting, casting, rolling, stretching, power bending grading, quality control	round, square and twisted steel bars of various dimensions	slag, steel metal cuttings (to be recycled), poisonous gases (CO, H_2S) heat	wastewater containing heavy metals, oil films on wastewater, slag containing metal, dust and fumes heat, poisonous gases
Chillington Tool Co. Ltd.	Steel flat bars (200 t·month^{-1}) metal pipes, metal straps, mild steel sheets, paint, vanish, xylene machete blanks, timber off cuts, grease & oil lubricants NWSC water (14 m^3 ·d^{-1})	many production processes such as cutting, shearing, furnace heating, squeezing, pressing, ribbing, rolling, spreading, chopping, holing, marking, finishing	hand hoes assorted (6 000·d^{-1}) wheelbarrows, slashers	Scrap metal (28 t·month^{-1}), metal chips, hoe trimmings metal dust, burnt furnace oil, fumes of oxides of iron, copper and organic solvents	wastewater containing heavy metals, oil films on wastewater, metal containing slag, dust and fumes, heat, poisonous gases
Leather Industries of Uganda	Fresh cow and goat skins (550 kg day^{-1}) Chemicals: chromosol, acetic acid, sulphuric acid, sodium carbonate, ammonium sulphate, sodium bisulphite, sodium chloride, chromium sulphate, caustic soda, sodium sulphide, lime, sodium sulphate aluminum sulphate, calcium hydroxide & manganese sulphate for precipitation & desludging NWSC water (15 m^3 day^{-1}), lake water (10 m^3 day^{-1})	weighing, salting, soaking, liming, tanning desludging, deliming, precipitation, packaging, selling (export)	Semi finished leather, wet blue cow & goat leather, finished leather bicycle seats, bags, belts, shoes	Sodium sulphide, chrome cake, lime sludge cake, fleshings	Chromium cake, spills and leakage of raw materials Note: aeration of oxidation ponds, bad & toxic odors of NH3 & H2S, volatile organics on-site in-filling of chrome cake
Oxy-Plastics Ltd.	High density polyethylene for blow and injection molding, low density polyethylene water (1.7 m^3 day^{-1})	mixing, heating, cooling, remelting polythene granules, recycling plastic trimmings	Plastic jerry cans, plates, mugs, pharmaceutical and laboratory plastic ware	Plastic trimmings, organic gases (CxHy), steam	none Note: not active

Data presented were obtained from questionnaires and site visits

All of the surveyed companies are listed in Table 1; the ones selected for further analysis are characterised in Tables 2 and 3, based on interviews and on-site discussions. These tables provide approximate quantities of the materials' flow through the production processes of the various types of industries, and illustrate the large variety of usable or waste by-products and polluting compounds that are present in the wastewater. Wastes from food-processing activities consist mainly of organic substances, such as blood, fat, skins, bones, or other residues from grain and bread processing. The tannery of fish and cattle skins results in wastewater containing chromium. Effluents from metal or chemical industries contain hazardous compounds, mainly heavy metals, gases, as well as dust and waste heat. Table 4 illustrates the daily water use and wastewater discharge volumes, demonstrating that food-processing industries clearly produce larger quantities of solid waste and wastewater than metal and chemical industries and these can be expected to pollute the wetlands and the water of Lake Victoria. The NWSC Kirinya Pond acts as an oxidation pond (purification pond) for the city of Jinja and most of the industries of the area; the average volume of its wastewater discharge to Lake Victoria is approximately 15 times the sum of the industries monitored in this project.

The daily time course of the on-site measurements of the physical parameters indicate that the concentrations and loads of polluting compounds vary during the day; in many cases this variation can be very wide. This is best seen in the mean values with the corresponding standard deviation (from between 11 and 40 sampling data points, Table 5). As expected, the outflow of the large NWSC purification pond has a considerable buffering capacity. Parameters related to primary production showed almost constant values for the 4 parameters temperature, pH, conductivity and DO, and the values of these parameters in the effluent from the NWSC pond were very similar to those measured in the swamps and the open water of Lake Victoria (Lindenschmidt et al., 1998; Campell et al., 2003). Effluent temperatures ranged quite widely, between 20 to 35°C, indicating either the use of hot water (Steel Mill, Kengrow Industries Ltd, a food processing factory, and the leather industry) or of ice (Gomba Fishing and Agro-Marine), since the temperature in the lake water remains within 23 and 27°C during the year (Lindenschmidt et al., 1998; Campell et al., 2003). The pH values were mostly neutral to slightly alkaline, except for effluents from the Kengrow and leather industries where mean pH values increased to around pH 9.9, with peak values up to pH 11. Conductivity, used as a measure of the concentration of total dissolved salts, varied considerably in wastewater from food processing, ranging between 100 and 400 $\mu S \cdot cm^{-1}$, except during those times when the facility was being cleaned. In contrast, wastewater from the leather industry as well as from Kengrow showed peaks of waste release with values reaching 70 $mS \cdot cm^{-1}$; this resulted in standard deviations that were larger than the corresponding mean values. The tanning industry uses large amounts of ammonium sulphate, calcium oxide, sodium chloride and sodium sulphide for the process. The steel industry (Chillington; Steel Rolling Mills) showed only small changes in all parameters. Fish processing results in high organic loads, and it is therefore not surprising that the DO concentration had practically dropped to zero at one sampling site in the factory oxidation pond (Gomba 2). In addition, the leather Industry produces high organic loads that also diminish DO concentrations in water; this also holds true for the wastewater from the Kengrow and Uganda Bread bakery. Variations in all parameters were similar during the day and night samplings at industries that operated continuously over a 24 h period.

TABLE 4
Annual daily average water use and discharge at point sources (July 1997 to August 1998)

Company	Water use ($m^3 \cdot d^{-1}$)	waste-water discharge ($m^3 \cdot d^{-1}$)
Agro-Marine Export Processing Co. Ltd.	123	95
Chillington Tool Co. Ltd.	14	10
Gomba Fishing Industries Ltd.	176	136
Kengrow Industries Ltd.	23	17
Leather Industries of Uganda	17	13
Steel Rolling Co. Ltd.	9	6
Uganda Bread Ltd.	28	21
NWSC Wastewater Kirinya pond	5 754	4 443

Pollution loads into the wetlands and Lake Victoria from the different sources were estimated for the nutrients nitrogen and phosphorus, while COD and BOD were used as surrogate measures for organic carbon (Table 6).

While the latter parameters are low in the effluent from the NWSC pond, they are high in effluents from food- and hide-processing industries, with average COD values exceeding 3 800 $mg \cdot \ell^{-1}$, with occasional extreme values up to 19 000 $mg \cdot \ell^{-1}$ for Kengrow (Fig. 2c), and 500 $mg \cdot \ell^{-1}$ for the leather industry. For wastes from fish processing, the COD concentrations ranged between 65 and 825 $mg \cdot \ell^{-1}$, with a mean of 222 ± 168 $mg \cdot \ell^{-1}$ for Agro-Marine and a mean of 177 ± 110 $mg \cdot \ell^{-1}$ (ranging between 40 and 670 $mg \cdot \ell^{-1}$) for Gomba fish processing (Table 6). Rapidly biodegradable carbon, as represented by the BOD_5 values, was also high in wastewater from Kengrow and leather industry with a mean of 475 and 140 $mg \cdot \ell^{-1}$, respectively. Food-processing industries had also high levels of nitrogen compounds; surprisingly, the highest values for ammonia were found in the efflux from the NWSC wastewater pond into the wetlands. Sources of soluble phosphorus were mainly the fish, food and leather industries, while the steel industry plant contributed negligible quantities of soluble reactive phosphorus.

Concentrations of heavy metals in wastewater were generally low with the exception of the leather industry, where chromium is used in the tannery process. The presence of manganese in metallurgic wastewater was expected. The high value from Uganda Bread, which exceeded the guidelines, originated from sources that were located outside the bread bakery. Table 6 also lists the guidelines of the World Health Organisations (WHO, 2004) and the standards for discharge of effluents in Uganda (1995) for comparison.

Figure 2 illustrates the very high variations recorded in the concentrations of some selected parameters. The temperature

TABLE 5
Mean values and standard deviation of physical parameters at wastewater outlet (number of measurements)

Sampling site	Temperature (°C)	pH	Conductivity ($\mu S \cdot cm^{-1}$)	Dissolved oxygen ($mg \cdot \ell^{-1}$)
Agro-Marine Export	23.6 ± 2.8 (30)	7.8 ± 0.6 (28)	395 ± 166 (30)	4.8 ± 0.9 (24)
Gomba Fishing Industries (Channel 1, fish filleting discharge)	21.5 ± 2.3 (44)	7.8 ± 0.3 (40)	176 ± 151 (45)	4.2 ± 0.8 (43)
Gomba Fishing Industries (Channel 2, effluent to NWSC pond)	23.9 ± 1.1 (27)	7.5 ± 0.1 (11)	280 ± 231 (27)	0.7 ± 0.4 (27)
Kengrow Industries	30.6 ± 6.3 (28)	9.9 ± 1.9 (20)	6 581 ± 14 800 (28)	2.3 ± 1.1 (27)
Uganda Bread (Channel 1, boiler house)	26.9 ± 2.4 (32)	8.0 ± 0.6 (32)	104 ± 17 (32)	4.4 ± 1.1 (32)
Uganda Bread (Channel 2, factory washings)	24.2 ± 1.2 (32)	7.7 ± 0.9 (32)	338 ± 262 (32)	3.8 ± 0.6 (32)
Uganda Bread (Channel 3, outside factory)	25.5 ± 1.8 (32)	7.4 ± 1.0 (32)	342 ± 154 (32)	3.0 ± 1.0 (32)
Steel Rolling, (small Mill 1)	31.4 ± 1.2 (24)	7.6 ± 0.5 (23)	1 274 ± 45 (23)	3.1 ± 0.6 (23)
Steel Rolling, (large Mill 2)	32.0 ± 2.0 (23)	7.5 ± 0.5 (23)	1 486 ± 76 (23)	4.3 ± 0.6 (23)
Chillington, (Channel 1)	27.9 ± 3.7 (20)	7.1 ± 0.4 (13)	343 ± 89 (20)	3.9 ± 1.2 (19)
Chillington, (Channel 2)	24.7 ± 1.4 (21)	7.0 ± 0.3 (13)	384 ± 122 (20)	3.1 ± 1.1 (19)
Leather Industries	29.2 ± 2.3 (26)	9.0 ± 2.6 (26)	5 950 ± 8 740 (26)	1.4 ± 1.4 (26)
NWSC Wastewater Kirinya pond, (final outlet)	28.2 ± 0.7 (43)	7.8 ± 0.7 (29)	649 ± 84 (41)	6.1 ± 1.6 (42)

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TABLE 6
Summary of selected chemical parameters at point of discharge in relation to the standards of discharge of effluents in Uganda, and WHO, 1984 drinking water guidelines. All values in mg·ℓ$^{-1}$. Mean values and standard deviation was calculated from at least 20 samplings.

Selected parameters	Industries involved	Mean values	WHO[#]	[+]Uganda
Chemical oxygen demand (COD)	Agro-Marine	222 ± 168	-	100
	Gomba	177 ± 110		
	Kengrow	3 877 ± 5 024		
	Leather	506 ± 664		
	NWSC pond	14 ± 5		
Biological oxygen demand (BOD_5)	Agro-Marine	61 ± 71	-	50
	Gomba	398 ± 179		
	Kengrow	475 ± 155		
	Leather	140 ± 74		
	NWSC pond	30 ± 12		
NH_4-nitrogen	Agro-Marine	2.6 ± 1.2		
	Gomba	6.0 ± 12.3		
	Leather	6.4 ± 4.9		
	NWSC pond	10.8 ± 2.3		
NO_3^--nitrogen	Agro-Marine	10.8 ± 2.3	-	10
	Bread	4.8 ± 4.8		
	Kengrow	6.7 ± 8.0		
	Leather	7.8 ± 4.4		
Soluble reactive phosphorus	Agro-Marine	11.5 ± 5.6	-	5
	Kengrow	5.5 ± 4.5		
	Leather	1.5 ± 1.2		
	Steel Rolling	0.03 ± 0.04		
	NWSC pond	2.4 ± 1.1		
Copper (Cu)	Bread	0.03 ± 0.02	2.0	1.0
	Chillington	0.13 ± 0.13		
	Steel Rolling	0.23 ± 0.05		
	NWSC pond	<0.01		
Chromium (Cr)	Bread	0.22 ± 0.06	0.05*	0.05
	Leather	264 ± 499		
	Chillington	0.15 ± 0.03		
	Steel Rolling	0.26 ± 0.03		
	NWSC pond	<0.02		
Lead (Pb)	Bread	0.05 ± 0.1	0.01	0.1
	Chillington	0.03 ± 0.06		
	Steel Rolling	<0.05		
	NWSC pond	<0.02		
Manganese (Mn)	Bread	0.91 ± 0.71	0.4	1.0
	Chillington	0.37 ± 0.41		
	Steel Rolling	0.28 ± 0.04		
	NWSC pond	<0.02		
Nickel (Ni)	Bread	0.22 ± 0.07	0.02*	1.0
	Chillington	0.10 ± 0.01		
	Steel Rolling	0.30 ± 0.03		
	NWSC pond	<0.02		

*[#]WHO Guidelines, 3rd edn. (2004), [+]Standards of discharge in Uganda (1999), * Provisional values.*

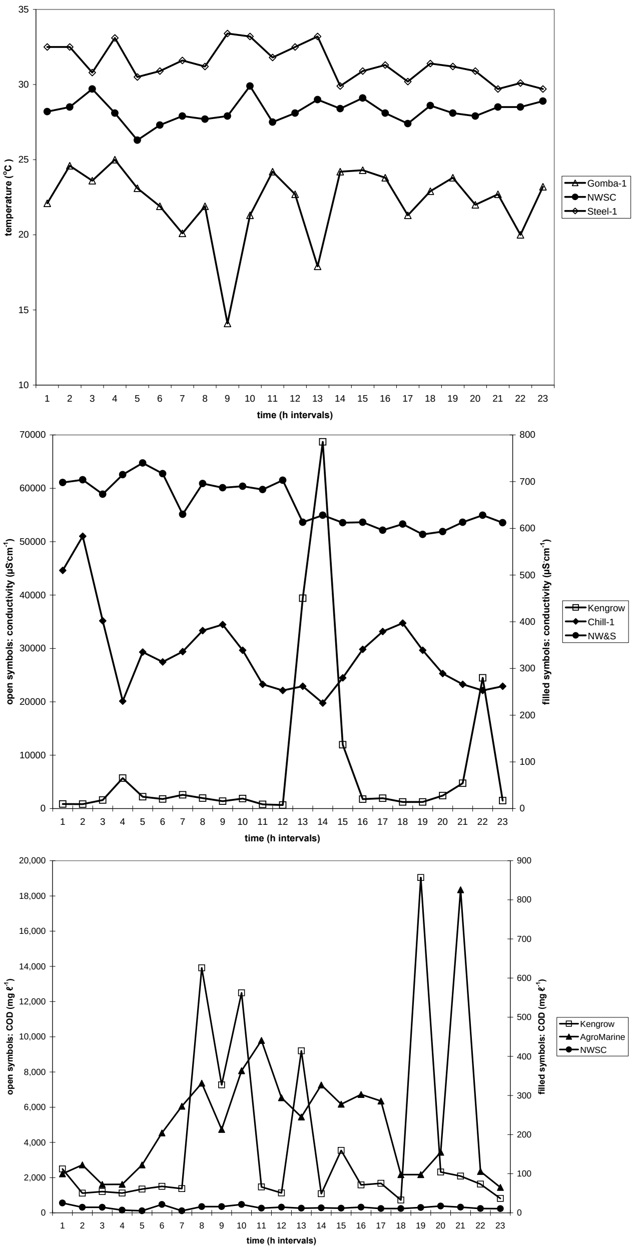

Figure 2
Time course of selected parameters at selected point sources. Measurements in intervals of one hour, plotted consecutively from different sampling days.
a) temperature (°C)
b) conductivity (µS·cm^{-1})
c) COD (mg·ℓ$^{-1}$ O_2)
For each sampling site several individual measuring periods over 12 months in 1997/98 are presented in sequence. Sampling occurred between 8 am and 10 pm. Due to the distances between the sampling sites, the samplings were at different dates and times, thus the curves in the graphs cannot be time correlated.

of the NWSC effluent follows the ambient temperature of the site. In contrast, fish-filleting industries (Gomba) need refrigerators and use ice, therefore the mean effluent temperature is always lower than NWSC; a sudden drop in effluent temperature to 15°C demonstrates the disposal of a large batch of cold water or melted ice. In contrast, the temperature of the effluent from metal industries (Steel Rolling Mills) is always higher than the water temperatures in the NWSC pond. The effluent of the NWSC pond has an average conductivity of 600 to 700 µS·cm^{-1}, with little variation, and depends mostly on the variable inputs of effluents from the different industries. In the metal industry (Chillington), conductivity values were rather low, ranging between 300 to 500 µS·cm^{-1}. The conductivity values of effluent from the food-processing plant operated by Kengrow are normally between 500 to 2 000 µS·cm^{-1}, though very high values up to 70 000 µS·cm^{-1} were recorded from time to time. The precise

TABLE 7
Estimation of annual pollution load from different point sources from industries in Jinja (kg·yr^{-1})

Chemical compound	Agro Marine	Gomba Fishing	Kengrow Industries	Uganda Bread	Steel Rolling	Chillington Co. Ltd.	Leather Industries	NWSC Kirinya pond
Nitrogen NO_3-N	*	133	*	32.1	15.3	0.2	26	84 260
Nitrogen NH_4-N	98	197	29	1.3	0.2	0.5	19	16 750
Phosphorus (SRP) PO_4-P	485	774	48	1.1	0.1	0.4	4	3 885
BOD	2 700	14 490	4 000	162	14.2	14.8	365	48 530
COD	10 850	5 630	36 790	*	*	*	745	22 170
Copper	*	*	*	0.4	1.4	0.6	*	1.6
Nickel	*	*	*	1.5	1.7	0.4	*	*
Chromium	*	*	*	2.1	1.5	0.5	2’170	3.2
Lead	*	*	*	1.6	0.4	0.2	*	16.0
Cadmium	*	*	*	0.1	*	*	*	*
Manganese	*	*	*	10.0	1.6	1.8	*	*

Loads were calculated from concentrations of mixed samples (equal volumes every hour for 12 h·d^{-1})
** = not calculated because the concentrations determined were below or at the detection limit.*

cause of this variation is not known but it is probably due to the effect of periodic cleaning of the processing unit.

From the amounts of wastewater disposed and the concentrations of the various chemical parameters determined in the different effluent streams, estimates were made of the annual loads of waste compounds deposited in the wetlands and Lake Victoria. These loads are summarised in Table 7. Gomba Fishing Industries Ltd. with its inefficient treatment pond showed much higher nutrient loads for nitrogen and phosphorus when compared with Agro-Marine. Kengrow Industries Ltd., a food-processing factory that discharges oily and soapy effluents and lacks any on-site effluent pretreatment, discharged the highest organic load of 36.8 t·yr^1 of organic carbon equivalents measured as COD. Leather Industries of Uganda discharged an estimated amount of 2.2 t·yr^1 of highly toxic Cr^{+6}. The measured chromium concentrations exceeded the maximum permissible limit of 0.05 mg·ℓ$^{-1}$ Cr^{+6} by a factor of more than 5 000. In contrast, the metallurgy point sources of Steel Rolling Mills and Chillington released only small traces of the metals Copper, Lead, Nickel, Cadmium and Manganese. The concentrations that were measured in effluents were all below the maximum permissible limits. The Kirinya maturation pond, part of the NSWC public sewer and linked with the urban drainage system, contributed high loads of nutrients that will certainly contribute to the eutrophication of Lake Victoria. The final effluent discharged from the NSWC pond contributed 3.9 t·yr^1 of phosphorus and 85 t·yr^1 of nitrogen into Kirinya West urban wetland during an annual cycle.

Discussion

Chemical pollution and high inflowing nutrient loads from increasing effluent discharges from urban centres along the lake shore are the main environmental factors leading to the degradation of Lake Victoria, an extremely important source of food and water for about 28 x 10^6 people (Ogada et al., 2004). Industries producing wastewater are situated in towns bordering the lake; in Uganda, these are mainly from Kampala and Jinja. Industrial wastewater treatment plants are generally lacking in Uganda and wastewater is drained into the wetlands (Scheren et al., 2000). The various point sources originating in industries close to the wetlands of Lake Victoria pose a strong pollution impact upon the water quality of the lake. The two fish-filleting companies released fresh fish remains and blood into their waste effluents; while the wastewater from Steel Rolling Mills had high salt concentrations, contained slag particles and had elevated temperature. Chillington discharged water that was enriched in salts in addition to metal oxide fumes, gases, heat, and oily wastes. The disposal of toxic chromium by the leather industries is very harmful, as well as the release of volatile organic compounds and toxic hydrogen sulphide. All of these industries had effluents that contained polluting compounds in concentrations well above the allowed values. Leather industries discharged peaks of up to 1 250 mg·ℓ$^{-1}$ of the toxic Cr^{+6}, exceeding the permissible limit of 0.05 mg·ℓ$^{-1}$ by a factor of more than 25 000 times (NEMA, 1999). Although mean concentrations of copper, nickel, lead and manganese at point sources of metal industries were below the maximum permissible limits, peak values were often up to 10 times higher. As Lake Victoria has an extremely long flushing time, contaminants remain in the water and sediment for long periods. With time, toxic metals are likely to enter the food chain and accumulate in biomass causing cumulative effects in fish-eating organisms including man. The accumulation of metals was higher in shallow near-shore regions and river mouth areas, especially those located close to urban sites (Mwamburi et al., 1997). Long-term effects of toxic compounds on the Lake Victoria ecosystem are poorly understood. Discharge of aluminium sludge from drinking water treatment facilities into wetlands has had a great negative effect on growth of *Cyperus papyrus*, the dominant macrophyte of economic value in Lake Victoria wetlands (Kaggwa et al., 2001).

The high concentrations of the nutrients P and N are important contributors to the increasing eutrophication of Lake Victoria (Hecky and Bugenyi, 1992; Hecky, 1993; Hecky et al., 1994; Mugidde, 2001). Indeed, the continuing proliferation of the water hyacinth, *Eichhornia crassipes*, in the Ugandan part of Lake Victoria has been linked to the increasing nutrient loads to the lake from the urban and industrial centres (Verschuren et al., 2002; Ogwang and Molo, 2004). Studies on Lake Victoria in the region of Kisumu (Kenya) revealed much higher loads of carbon, phosphorus, nitrogen and metals (Kiragura and Nevejan, 1996) compared to the loads recorded in this study in Uganda. This is probably due to the more industrialised situation around Kenya’s Nyasa Gulf, with large tea and sugarcane farms. Water use in industries is substantially higher in Kenya and Tanzania, compared to Uganda (Orindi and Huggins, 2005). However, with the present growth of the Uganda population, a parallel increase in industrial activities is expected to occur. This is likely to rapidly

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increase the pollution and eutrophication originating in the Jinja region to the levels found in Kenya (Scheren et al., 2000).

Wetlands have been shown to be important for wastewater purification, since they absorb soluble and particulate nutrients and form a buffer between the land and the open water. However, due to diffuse water flows and uncontrolled channel formation, the purification efficiency of wetlands is often difficult to evaluate and is also very often low. A model study of the buffering capacity suggests that phosphorus is strongly retained within wetlands, while organic matter and nitrogen (as nitrate) are mostly exported into the lake (Mwanuzi et al., 2003). In many places, wetlands disappear or degrade, mainly through human activities (Balirwa, 2002). As a consequence, large shifts in biodiversity are observed in the wetlands as well as in aquatic communities in the lake. With time, continuing wetland degradation can be expected to cause a progressive decline in the types and quantities of benefits and services that these wetlands provide to the local population, including their roles as sources of food and raw materials, as habitat for wildlife, and for hydrological stability.

Conclusions and recommendations

This paper has focused on a small number of significant pollution point sources which illustrate the urgent need for on-site effluent pretreatment and continuous monitoring of industrial effluents in Uganda. With the present primitive process technology, fish filleting at Gomba and Agro-Marine and Kengrow Industries will continue to enrich Napoleon Gulf with key nutrients and easily degradable carbon compounds, leading to further oxygen depletion in Lake Victoria. The Leather Industries of Uganda plant discharges high loads of toxic Cr^{+6}; this substance is likely to accumulate in the wetlands and pollute Napoleon Gulf if it is not treated at the plant. Except for Gomba and Leather Industries of Uganda, the companies monitored in this study lacked any on-site pretreatment system. This is a situation that should alert the Uganda National Environment Management Authority to enforce Uganda's National Environment Statute (NEMA, 1995).

With increased urbanisation and socio-economic activities in Jinja's industrial sector, the load of nutrients and pollutants entering Lake Victoria will continue to increase and further diminish the quality of the lake water. Introduction of cost-effective cleaner production technologies must be enforced, such as on-site waste separation and reduction, and effluent recycling, coupled with an urgent requirement for increased and compulsory training of the personnel at industrial plants and the proper maintenance of the treatment facilities. The overall environmental management strategy for Jinja has also to insist on a broad multidisciplinary approach including acting on the behaviour of the population because people living in the catchment area act simultaneously as resource users and as polluters (Bugenyi and Balirwa, 1989). The Lake Victoria environmental management project, LVEMP, which was started several years ago, has already concentrated on some of these problems, and its activities will further assist in reaching the goals envisaged (Orach-Meza, 2001; UN-HABITAT, 2004).

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