

## CHAPTER 10

### Agricultural chemicals and metal contaminants in the Ugandan catchment of Lake Victoria

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**ABSTRACT.** Use of agricultural chemicals in the Lake Victoria catchment has increased in recent years. The increasing level of environmental degradation reflected in loss of vegetation cover, biomass burning, encroachment on protected areas, and accelerated soil erosion pose a serious environmental concern due to non point pollution in the atmosphere, soil and aquatic ecosystems. Studies under the Lake Victoria Environmental Management Project (LVEMP) and other international investigators have revealed gross abuse and misuse of agricultural chemicals in Uganda. Many restricted chemicals are being used by untrained persons while adulteration of some is common. A number of banned organochlorinated pesticides (e.g. DDT, endosulfan, dieldrin and lindane) were detected in air showing that they may still be in use in the Lake Victoria basin. However, these pesticides were not detected in sediments, water or fish tissue. Studies also showed that herbicides Touch Down (48% Glyphosate trimesium) and Gasepax (2,4-D and Ametryne) used in sugarcane cultivation pose no environmental threat in runoff water, soil and fish, four months after field application. Elevated metal concentrations (Mn, Zn and Cr) detected in some rivers were, related to industrial activities or runoff from urban areas, therefore calling for controlled waste disposal. High Total Hg concentrations were higher in recently deposited lake sediments than older ones, indicating increased environmental degradation. Nevertheless, Hg concentrations in sediment, water and fish from Lake Victoria were below the WHO and international environmental guidelines. These results call for more stringent measures to control the types of agricultural chemicals used in the catchment coupled with massive sensitisation of communities on safe handling and use of agrochemicals. Collective efforts to promote better land husbandry practices, industrial and municipal waste disposal and management should be enforced in the entire Lake Victoria catchment to curb land degradation and biomass burning that contributes to non point pollution.

**Key words:** Pesticides, non-point pollution, heavy metals, mercury, fish contamination.

## INTRODUCTION

Agricultural chemicals as used in this report include pesticides as well as fertilizers. The national rate of inorganic fertilizer application is relatively low in Uganda, largely controlled by the cost of the materials and low profitability of farming for the small scale farmer. Although agricultural applications potentially add to the nutrient loading to Lake Victoria, other sources including atmospheric deposition of ash, dust and soil erosion are much greater contributors to the nutrient loading of Lake Victoria. Pesticides however can be a concern even at low national rates of application if they are used inappropriately. Pesticides are biocides and can have significant effects on non-target organisms. In North America unregulated use, particularly of organochlorines in post World War II led to widespread contamination problems including the North American Great Lakes, with documented damage particularly on fish eating birds and mammals because of bioaccumulation of persistent organochlorines. Banning and removal from use has led to a recovery in the Laurentian Great Lakes of many affected

animal populations but fish eating advisories for humans related to levels of contamination remain in effect on many of the lakes (Mason, 2002). Given the importance of fisheries to the national diet and to the export economy in Uganda, similar contamination by organochlorines must be avoided and LVEMP and other international investigators have undertaken studies to define the current situation in Lake Victoria.

### **Monitoring of Agro-chemicals in use**

A major problem identified during LVEMP preparation was the lack of adequate information on the nature and quantities of agrochemicals in use in the Uganda Lake Victoria catchment. This problem may not stem so much from the quantities used but from the types and manner of use. During the period 1999-2004, data on types and quantities of agro-chemicals used in the Lake Victoria catchment areas of Uganda were collected. To reflect use by small-scale farmers, data was gathered from stockists and dealers in the major riparian district towns. For large-scale farmers, data was collected directly from the farms given the fact that these directly imported their own agro-chemicals.

### **Agro-chemicals database**

All acquired data on use of agrochemicals was entered into a computerised database established at Kawanda Agricultural Research Institute (KARI), Uganda (Mubiru *et al.* 2004). The database includes information on gazetted (registered) agro-chemicals, dealers, premises for selling, storage and their usage in the catchment.

Synthetic pyrethroids, organophosphates and fertilisers containing N, P and K were the most widely and abundantly used agro-chemicals. However, records also showed continued use of chlorinated pesticides, which had long been banned. A monitoring programme to analyse pesticides in the atmosphere also confirmed use of chlorinated pesticides, even those that were not recorded during the survey of currently used pesticides. This atmospheric monitoring may be illustrating the volatilization of previously used banned chemicals from soils as well as possibly illicit current use. Adulteration of pesticides was a common practice and most dealers did not store the chemicals in the recommended way. Sale of unregistered chemicals was a common practice. Sensitisation of stakeholders on safe handling and use of agrochemicals was carried out in the entire Uganda Lake Victoria catchment districts. Pamphlets and posters on safe and appropriate use of agrochemicals were printed and distributed by LVEMP to try to improve the usage and handling of these compounds by farmers and stockists.

The use of agro-chemicals also differed significantly in the floricultural sector. Most floriculturalists use methyl bromide, a cheaper but less environmentally friendly soil fumigant whose use is restricted due to its halogen-induced ozone destruction properties (Spiro and Stigliani, 1996). Because of the need to comply with the Milieu Project Siertealt (MPS) standards prerequisite to accessing the European Union (EU) market, flower farms growing chrysanthemums are gradually switching from methyl bromide to other fumigation methods such as steaming and/or use of metham sodium. These latter options are more environmentally friendly but expensive.

In regard to the types and manner of use, there are some organochlorinated pesticides such as endosulfan still in use, and, since 1994, there have been 34 formulations in the restricted-use classification that were registered with the Agricultural Chemicals Board (ACB) (Table 10.1). Chemicals in the 'restricted use' classification require certified applicators. However, it was established that there were no certified applicators in Uganda. Without access to trained, certified applicators then the restricted chemicals are more likely to end up in the hands of non-trained people and the chances of misuse are therefore very high. Further training and continued dissemination of information on appropriate use is required to reduce the risks to individual users and non-target organisms and especially aquatic resources. In the past, inappropriate use of agrochemicals to poison and harvest fisheries resulted in closure of the

fishery export of Lake Victoria to the EU market with great economic consequences to Uganda. This illustrates the need for suitable information dissemination program to address the public as well as the farming groups in order to sustain public pressure for appropriate use.

**TABLE 1. Pesticides on the EPA<sup>a</sup> restricted-use list registered in Uganda<sup>b</sup>**

Pesticide	Category	Trade Name	Restricted Uses	Criteria for Restriction
Aluminum phosphide	Fm	Phostoxin	All	Inhalation hazard
Amitraz	I, M	Baam	All	Possibly oncogenic
Carbofuran	I, A, N	Furadan	> 40%	Inhalation toxicity
Chlorfenvinphos	I	Supona	>21%	Dermal toxicity
Cypermethrin	I	Ammo, Cymbush	>30%	Oncogenic, non-target hazard
Ethion	I, A		All	Acute toxicity
Fenamiphos	N	Nemacur	>35%	Dermal and inhalation toxicity
Fenitrothion	I	Sumithion	All	Possible wildlife effects
Fenvalerate	I	Pydrin	>30%	Aquatic organism effects
Monocrotophos	I, A	Azodrin	>19%	Dermal and non-targets
Oxamyl	I, N, A	Vydate	All	Oral and inhalation toxicity
Paraquat dichloride	H, D		All except several dilute pre-mixtures	Human toxicity and accident history
Permethrin	I	Ambush, Pounce	All	Aquatic organism effects
Profenophos	I, A	Curacron	>59.4%	Corrosive to eyes
Zinc phosphide	R		10%	Oral and inhalation toxicity

<sup>a</sup>EPA refers to Environmental Protection Agency (USA).

<sup>b</sup>The pesticide category to which the chemical belongs is designated as follows: A, Acaricide; D, Desiccant; F, Fungicide; Fm, Fumigant; H, Herbicide; I, Insecticide; M, Molluscicide; N, Nematicide; R, Rodenticide.

## Persistence of selected pesticides in the Lake Victoria catchment

### Introduction

Pesticide use in the Lake Victoria catchment of Uganda has continuously been increasing in recent years largely due to increase in the production of horticultural export crops and large sugarcane, tea and rice estates. These crops require use of pesticides for increased productivity and quality in order to meet market demands. However the use of these pesticides can pose risks to non-target organisms especially those with economic value. Pesticide measurements made on the fisheries have indicated that levels of pesticides are very low at present in the commercial fisheries catch, but the regulations in the export marketplace require continued monitoring and vigilance to protect the valuable export fishery market share of Uganda. World-wide, the general public is concerned about the potential environmental impact of pesticide use. This concern arises because many of the pesticides are semi-volatile and can be transported through the atmosphere to distant locations. Global efforts are underway to remove many of the more toxic, persistent and bio-accumulative pesticides, especially the organochlorines, from use. In the Lake Victoria basin, very few systematic studies have been conducted to monitor the impact of pesticides in use on the environment.

## MATERIALS AND METHODS

To understand freshwater pollution from agricultural activities in the Lake Victoria basin Wejuli *et. al.* (2003a) monitored herbicide levels in soils and water over a 304-day period following treatment of a sugarcane field in the northern Lake Victoria catchment. At Kakira Sugar Works in Jinja, the herbicide Touch down (Glyphosate trimesium) is used to control weeds in the Gleysols, soils found in valley bottoms and Gesapax H (2,4-D and Ametryne) is used to control weeds in the Nitisols, soils found on hill tops. The two herbicides were applied at planting. Touch Down (48% Glyphosate Trimesium) was applied in the Gleysol area in 2 splits of 2 weeks interval, at 6 litres/hectare. Gesapax H (21% ametryn and 29% 2, 4-D) was applied in the Nitisol area at 7 litres/hectare and again at the rate of 3.5 litres/hectare a week later. Soil and water samples were then collected at intervals after planting and herbicide treatment and analysed for herbicide levels. The water samples were collected at the point of discharge in the field and 100 meters down stream. Soil samples were collected over a depth of 10 cm. The water analytical results obtained were compared with the Canadian Environmental Quality Guidelines for fresh water, irrigation water and livestock water for selected pesticides. Soil quality guideline for the monitored pesticides were not available.

### Extraction and analysis

The pesticides were extracted from the soil using a 1:1 acetone:hexane mixture in a soxhlet extraction apparatus for 5 hours. The extracts were cleaned up using a column packed with florisil and eluted with 200 ml of 6% diethyl ether and then 200 ml of 15% diethyl ether. Glyphosphate was analysed using an HPLC with UV detector. The mobile phase consisted of 0.848g of  $\text{KH}_2\text{PO}_4$ /960 ml of water, 40 ml of methanol (HPLC Grade) brought to pH 1.9 by 85%  $\text{H}_2\text{PO}_3$ . The detection limit of the HPLC/UV using the detector response method was 0.08  $\mu\text{g}/\text{l}$  for glyphosphate. Ametryn and 2, 4-D were determined using Gas Chromatography with FID. The column type used was Ov-1 and the carrier gas was nitrogen. The detection limit, using the detector response method was 10  $\mu\text{g}/\text{l}$  for 2, 4-D and ametryn, respectively.

### Pesticide concentrations in soil and water

The relatively high levels of ametryn and 2,4-D found in soil a few days after planting (Table 2) were most likely due to the fact that samples were taken on the same day after the second application of the herbicide, Gesapax-H. The prior applied glyphosate generally had lower concentrations than ametryn and 2,4-D. Within the first 90 days after application, 2,4-D was at least 4 times higher than the fresh water minimum threshold (Canadian Environmental Quality Guidelines) as measured in the upstream and downstream portions of the nearby stream draining the sugarcane plantation. The presence of high concentrations upstream may indicate a general effect of herbicide application on nearby fields affecting water concentrations. The occurrence of lower concentrations downstream may result from dilution of those general inputs with accumulating flow. By 120 days after application, however, 2,4-D concentrations were undetectable in both the upstream and downstream portions of the monitored stream. Glyphosphate concentrations in water were all below the minimum threshold throughout the entire 304 days of monitoring in both the upstream and downstream waters. Overall, however, the general trend in dissipation for the three herbicides was similar and depended on sugarcane growth. A full canopy of sugarcane is normally attained 3-4 months after planting (depending on the variety and growth conditions such as rainfall and soil fertility). Dissipation of the pesticides was higher before the full canopy formation (before 120 days after planting). This is the time when the highest level of pesticides was lost through surface run-off. The high rate of dissipation in the first 120 days is most likely due to volatilisation and surface run-off.

Results of this study showed that compared with the global guidelines, at the applied rates the levels of herbicides touch down (glyphosate trimesium) and Gesapax-H used in the control of weeds in sugarcane farming at Kakira were below the tolerable levels in runoff water especially after 90 days following field application. In hot tropical environments, however, there is need to monitor pesticide loss through volatilisation after application especially during low crop canopy periods.

### Pesticide volatilization from treated fields

Wejuli *et al.* (2003b) measured volatilization fluxes of two pesticides, chlorpyrifos and malathion, from two soils following treatment of a sugarcane field in the northern Lake Victoria catchment. The fluxes were determined by placing flux chambers (plexiglass boxes) with inflow and outflow ports, on the soils following routine pesticide application. The pesticide concentrations in air were measured by passing the air in the chamber through a polyurethane foam (PUF) plug. The two pesticides together with their metabolites 3,5,6 trichloro-2-pyridinol (TCP), malathion di-carboxylic acid (MDCA) and malaoxon were analysed in extracts of the PUFs. The highest flux intensities were observed within 66 hours following application. The total cumulative losses at 143 hours for chlorpyrifos were 9.7 g/ha (red soil) and 10.2 g/ha (black soil) and, for malathion 0.154 g/ha (red soil) and 0.088 g/ha (black soil).

TABLE 2. Pesticide levels in soil and water following treatment of sugarcane field (Detectable limit: glyphosate = 0.08 µg/l; Ametryn = 15 µg/l; 2,4-D = 10 µg/l)

Days after planting	Soil			Water (up-stream)			Water (down-stream)		
	µg/kg dry soil			µg/litre					
	Glyph	Amet	2,4-D	Glyph	Amet	2,4-D	Glyph	Amet	2,4-D
2	0.14	Bd		0.2	bd	bd	bd	bd	bd
7	135.5	1705.4	835.2	0.4	bd	bd	0.3	bd	bd
20	59.8	991.4	583.3	22.4	31.5	15.7	9.3	18.6	13.4
54	171.7	569.2	265.5	42.2	17.5	13.8	25.0	15.1	12.2
90	69.3	225.4	176.6	13.6	15.4	12.9	9.2	bd	11.3
125	25.6	122.0	112.6	12.2	bd	bd	4.5	bd	bd
161	20.2	88.5	79.6	8.7	bd	bd	3.6	bd	bd
179	13.4	61.4	57.6	6.5	bd	bd	3.2	bd	bd
215	11.6	55.5	49.3	5.4	bd	bd	1.8	bd	bd
248	8.3	51.6	38.4	5.7	bd	bd	2.2	bd	bd
273	2.2	49.2	27.5	2.1	bd	bd	0.6	bd	bd
304	0.8	44.9	15.6	1.3	bd	bd	0.4	bd	bd
*Q Gd									
FhW				65	-	2.600	65	-	2.600
IrrW				-	-	0.025	-	-	0.025
LsW				280	-	25.000	280	-	25.000

\* Canadian Environmental Quality Guidelines (1999); Q Gd = Quality Guidelines; FhW = Fresh Water; IrrW = Irrigation Water; LsW = Livestock Water; Glyph = Glyphosate; Amet = Ametryn; bd = below detectable limit.

These were 0.34% (red soil) and 0.36% (black soil) of the application dose for chlorpyrifos, and 0.005% (red soil) and 0.003% (black soil) for malathion. The highest ambient air concentrations during sampling were also observed within 66 hours following application and were 3.9 µg/m<sup>3</sup> for chlorpyrifos, 0.85 µg/m<sup>3</sup> for TCP and 0.24 µg/m<sup>3</sup> for malathion. Soil organic matter and clay content, soil moisture dynamics, sunshine hours, relative humidity and rainfall influenced the levels of the flux intensities, and thus cumulative losses. However, there were no linear correlations as the influence of a combination of these factors varied from day to day. The fluxes were compared with fluxes of other

compounds measured elsewhere and although the application doses were doubled in this study, the fluxes into air were found to be relatively low (Table 3). It was concluded that volatilization may not present a major dissipation pathway in the short term for these two pesticides from the two major soils in the watershed.

## Atmospheric concentrations

### Introduction

Organochlorine pesticides may still be in use in the Lake Victoria basin for agricultural purposes and for control of mosquitoes, although their importation in Uganda was restricted between 1993-1999. Volatilisation from land and water surfaces and subsequent atmospheric transport and deposition pose environmental pollution risks to areas far from their sources of application. Degradation within the lake may be an important process for removal of these chemicals from the environment. It is therefore important to monitor the levels of these chemicals in the soil and aquatic environment and investigate their cycling processes within the lake region.

TABLE 3. Comparison of Pesticide Fluxes Observed from soil within 12-48 hours after application

Compound	Flux	Application Dose	Wind Velocity	Temperature	Method of Determination
	g/ha/day	g/ha	m/s	°C	
<b>Kakira sugar cane study site</b>					
Chlorpyrifos	5.1 (red soil)	2880	4.1	16.8-28.8	Flux Chamber
	4.8 (black soil)	2880	4.1	16.8-28.8	Flux Chamber
Malathion	0.05 (red soil)	2850	4.1	16.8-28.8	Flux Chamber
	0.02 (black soil)	2850	4.1	16.8-28.8	Flux Chamber
<b>Other studies (North America)*</b>					
Chlorpyrifos	22	1500	0.8-1.3	ns**	Micro-meteorological
Diazinon	6	1500	0.8-1.3	ns**	Micro-meteorological
Fonofos	1919	5300	ns**	11-32	Micro-meteorological
Lindane	242	1500	0.8-1.3	ns**	Micro-meteorological
p,p' DDT	11	1300	1.6-1.7	30-34	Micro-meteorological
Dieldrin	69	2500	0.08	5-3	Residue analysis***
Atrazine	20	2840	ns**	19-30	Micro-meteorological

\*Source Bedos *et. al.*, (2002); \*\* ns = not specified; \*\*\* Residue analysis of treated matrix

## MATERIALS AND METHODS

Atmospheric concentrations of organochlorinated pesticides in air were determined at Kakira and Entebbe on the shores of Lake Victoria, from November 1999 to 2004. Air sampling was done every week, on the eighth day after the previous sampling (to cover all the days of the week). Air samples were collected with a TE-PUF Poly-Urethane Foam High Volume Air Sampler (Tisch

Environmental Inc., Ohio, USA) using the US EPA Method T04. About 250 m<sup>3</sup> of air was drawn periodically through the sampling unit over a 24h cycle. Minimum and maximum temperatures, and wind direction were also recorded during sampling. Wet depositions were taken using an automatic sampler during each rainfall event.

The samples were sent to the National Water Research Institute, Canada for analysis. Detailed analytical procedures are described elsewhere (Strachan and Huneault, 1984; Hart *et al.* 1992; Environment Canada, 1999; Karlsson *et al.* 2000). The PUF plugs were extracted using a soxhlet apparatus with hexane or hexane/dichloromethane in a 1:1 ratio. Extracts were evaporated, the solvent changed to isooctane, and then further evaporated with nitrogen. Fractionation of samples was by column chromatography with either neutral silica (activated) or florisil (1.2% deactivated) eluted sequentially with mixtures of hexane and dichloromethane (Fellin *et al.* 1996; Environment Canada, 1999). One fraction contained chlorobenzenes and p,p'-DDE and the other chlorinated organic pesticides (Fellin *et al.* 1996; Environment Canada, 1999). Samples were evaporated to 1.0 ml with nitrogen.

Analysis was performed by gas chromatograph (GC) with <sup>63</sup>Ni electron capture detector (ECD) as described by Environment Canada (1999). Enantioselective analysis of  $\alpha$ -HCH was performed with a GC with a mass selective detector (MSD). Mass spectrometric and GC inlet conditions are described elsewhere (Muir *et al.* 1999). The instrumental detection limit for the organochlorine compounds was 0.1 pg/m<sup>3</sup> (Hoff *et al.* 1992). Data was compared with other sampling units in Malawi, Congo Brazzaville and Canada.

The levels of DDT (total) ranged from 64.8-610.9  $\times 10^{-12}$  g/m<sup>3</sup> (pg/m<sup>3</sup>), dieldrin 23.6-90.8 pg/m<sup>3</sup>, alpha-endosulfan 32.5-206.1 pg/m<sup>3</sup>, lindane 20.3-183.6 pg/m<sup>3</sup> while chlordane, heptachlor and hexachlorobenzene ranged from 0.0-10.1 pg/m<sup>3</sup>. The most prominent DDT isomers detected included the persistent insecticidal p,p'-DDT, p,p'-DDE and o,p'-DDT ranging from 19.2-390.1, 29.9-109.9 and 11.2-62.8 pg/m<sup>3</sup>, respectively (Figure 10.1). Presence of these chemicals in air at Kakira may be due to regional rather than local use, but the origin of these banned pesticides requires further study.

In Figure 2 pesticide concentrations at Kakira are compared with data from Lake Malawi/Senga Bay in Malawi and from a site (Pt. Petre) on Lake Ontario, an agricultural area in North America. Average levels of p,p'-DDT at Kakira were much higher than those reported for Pt. Petre (Karlsson *et al.* 2000). Lindane ( $\gamma$ -HCH), total chlordane, heptachlor and hexachlorobenzene (HCB) concentrations for Kakira were lower than those reported for Ontario. Average DDT (total), p,p'-DDT, p,p'-DDE, o,p'-DDT, endosulfan and lindane levels were higher at Kakira than in Malawi whereas average dieldrin, chlordane and HCB levels were lower. Kakira and Malawi were higher than the Lake Ontario site for most chlorinated compounds except for hexachlorobenzene, which is an industrial by product and an impurity in some pesticides.

### **Pesticides in water, sediments and fish**

In a recent investigation of the pesticide concentration in water, sediment and fish from Lake Victoria, no detectable levels of DDT, HCH, PCBs, Organophosphates, Pyrethroids and Malathion or their derivatives were found in all samples analysed (Fisheries Department, Uganda, 2000).

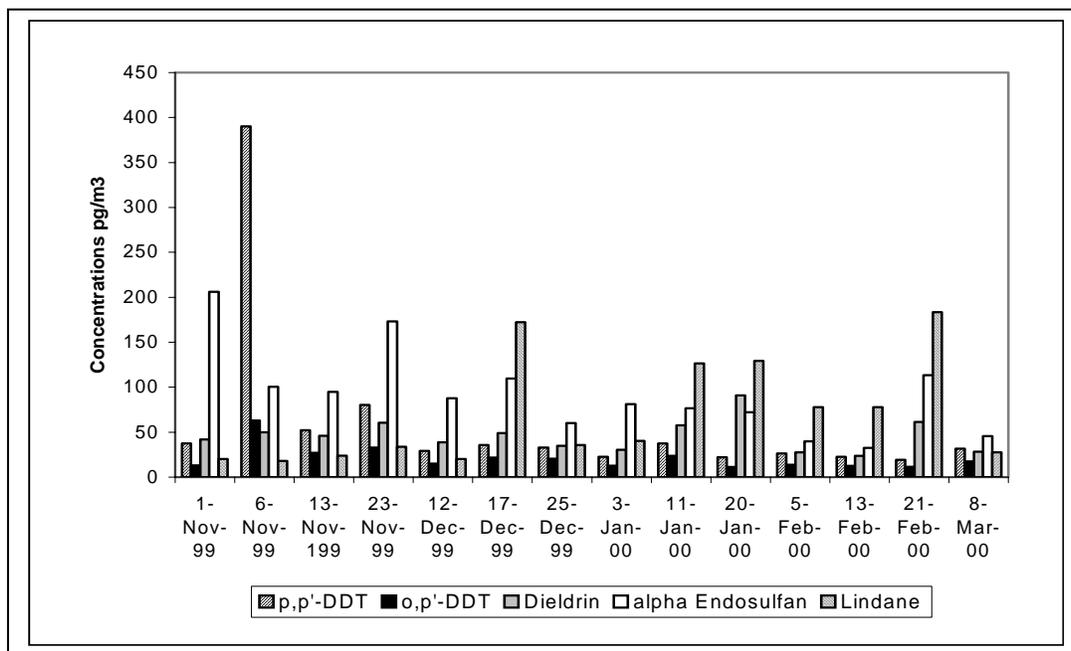


FIG. 1. Temporal atmospheric concentrations of chlorinated pesticides at Kakira, Uganda.

Atmospheric deposition studies from Kakira indicated that banned organochlorinated pesticides (such as DDT, endosulfan, dieldrin and lindane, among others) might still be in use in the region (Figure 1) and were definitely still available for atmospheric transport. Such chemicals may still be in use for control of mosquitoes in the catchment. Volatilisation from land and water surfaces and subsequent atmospheric transport and deposition may pose environmental pollution to areas far from their sources of application. Lipiatou *et al.* (1996) measured low but increasing concentrations of DDT and other organochlorines in a sediment core from Lake Victoria. The current concentrations pose little risk to aquatic biota, but the trend is cause for concern and continued monitoring of these contaminant residues in fish and other aquatic organisms is necessary to limit risk of significant contamination such as what occurred in the Laurentian Great Lakes and other aquatic ecosystems.

## Metal contamination

### Introduction

Heavy metals, e.g. cadmium (Cd), lead (Pb) and mercury (Hg), can be toxic to many organisms including humans. These metals are mobilized by human activities such as mining, combustion of fossil fuels, biomass burning as well as through specific uses in industrial processes. All these activities are increasing in the Lake Victoria catchment and therefore, these elements require monitoring to reduce risks to humans, other organisms, and aquatic ecosystems.

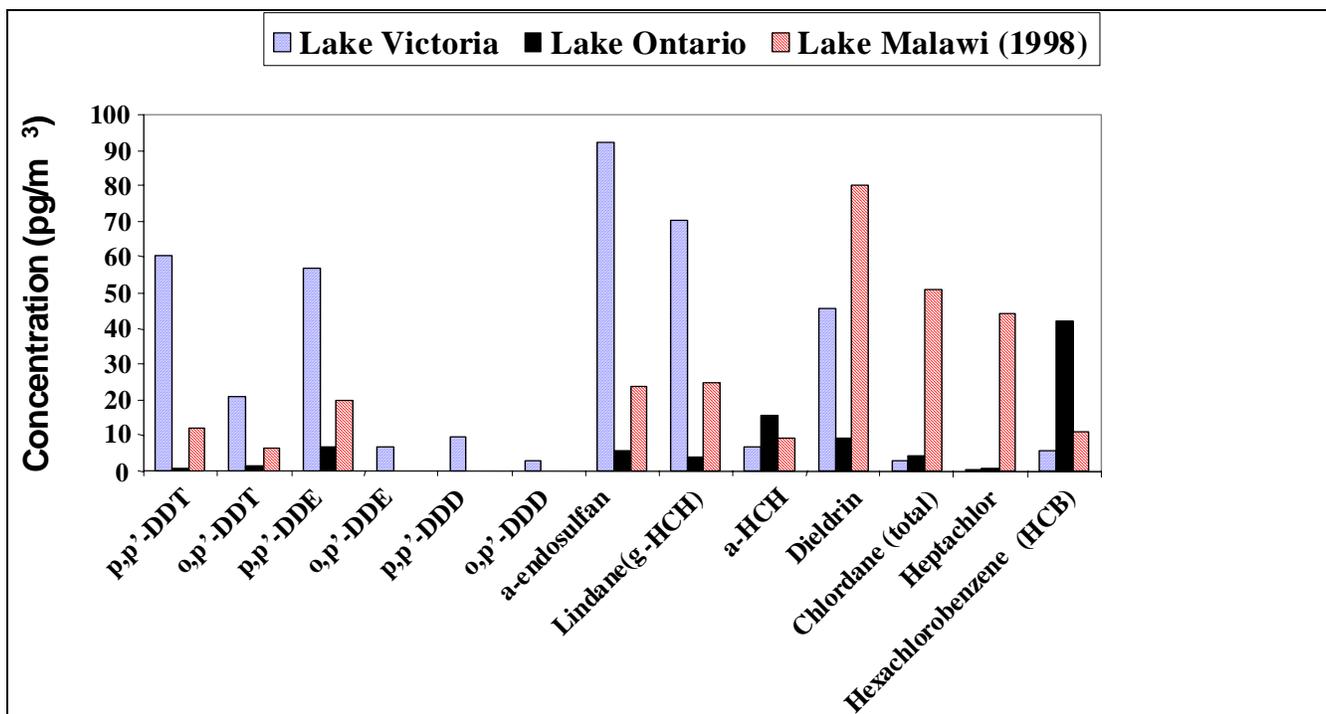


FIG. 2. Comparison of average ambient air concentrations of OC pesticides from Lake Victoria (East Africa), Lake Ontario (Canada) and Lake Malawi (Southern Africa).

Mercury in particular is a concern because it can be transformed from the inorganic metal into an even more toxic organic form, methyl mercury, by microbial activity in the aquatic environment. In the form of methyl mercury, mercury bio-accumulates in fish tissue and especially in muscle tissue. Methyl mercury is a powerful neurotoxin and most countries have set limits on acceptable concentrations in marketable fish. Lake Erie in North America had its fishery closed in the early 1970's because of mercury pollution from industrial sources, but concentrations in fish fell after removal of Hg from upstream industrial processes. Routine monitoring of mercury in Lake Victoria fish is now underway to insure that marketed fish have acceptably low concentrations of Hg.

### Processes and mechanisms affecting metal availability

Wetlands have the capacity to remove many heavy metals due to precipitation of insoluble metal compounds or removal of dissolved metals by exchange mechanisms favoured by the high ratio of root mat to water in wetlands. Matagi *et al.* (1998) observed that heavy metal removal by wetlands depends on a number of interacting physico-chemical and biological processes such as sedimentation, adsorption, co-precipitation, cation exchange, complexation, microbial activity and plant uptake. The extent to which these reactions occur is in turn determined by composition of the sediment such as types of clay, minerals, hydrous oxides, organic matter, sediment pH, redox status, nature of contamination and plant genotype. Despite the complexity of these interactions, there is little doubt that the extensive wetlands in the Ugandan portion of the Lake Victoria catchment do provide an important removal mechanism thus improving inflowing waters. In fact studies in Tanzania illustrated that wetlands were retaining Hg emissions from artisanal mining areas (Campbell *et al.* 2003a). However these metals can also be delivered directly to the lake surface through atmospheric deposition and

increases in metal deposition especially for Pb and Hg are well documented for locations far distant from any known point source.

It is possible that the tropical location of Lake Victoria provides some protection from Hg contamination. In warm tropical environments, solar radiation plays a key role in mercury transformation and in shallow near surface waters radiant energy can photo-reduce the inorganic cations of mercury to metallic Hg which is volatile and can escape from lake waters. This may have the benefit of accelerating the removal of Hg from the lake ecosystem and reducing the bio-available concentrations that can be methylated by bacteria in the lake. The low sulphate concentrations in the lake and consequently low activity of sulphate reducing bacteria may also provide protection from methyl mercury production as the sulphate reducing bacteria have been shown to be the most important bacterial group producing methyl mercury in most freshwater environments. However, varying redox conditions in different layers of the lake influence mercury availability, and may lead to formation of more MeHg and sulfides under anoxic conditions. Therefore, the increasing aerial spread of anoxic conditions in the lake (Hecky *et al.* 1994) may have some consequence for mercury cycling. According to Hecky *et al.* (1992), presence of wetlands surrounding a lake promotes anoxic conditions in waters passing through the wetlands, which can promote methylation of Hg by anoxic sulphate reducing bacteria. However this is apparently offset by the low concentrations of sulphate in surface waters in Lake Victoria catchment.

### **Causes/sources of metal contamination**

A number of land-based activities (such as mining, tannery, fish and other industrial processing) can potentially contribute to metal contamination in the aquatic systems. Although not well studied, the continued and growing use of leaded gasolines in East Africa similarly contributes to lead contamination in and near major urban areas (Nriagu 1992). Burning of biomass volatilises the previously bound Hg in terrestrial plants and soils into the atmosphere, which is recycled to the aquatic environment through runoff and deposition (Fitzgerald *et al.* 1998; Lockhart *et al.* 1998; Lucotte *et al.* 1999). This is likely the most important pathway adding Hg to Lake Victoria (Ramala *et al.* 2003; Campbell *et al.* 2003b). Nriagu (1992) estimated that 300 metric tons of Hg is emitted through burning of forests and savannas on the African continent every year. According to Ramlal *et al.* (2003), biomass burning associated with agricultural practices (cultivation, grazing) and charcoal production is likely the current major source of Hg to Lake Victoria. Increasing population or industrial activities puts pressure on the land for agricultural production and can produce industrial point sources of metal emissions. Land pressure results in more frequent and more extensive biomass burning in the Lake Victoria basin and this contributes to a global increase in atmospheric Hg concentrations above the baseline that has been documented around the world (Campbell *et al.* 2003c). Mercury can be transported over long distances even into the high latitudes of the Arctic before deposition (Fitzgerald *et al.* 1998; Lockhart *et al.* 1998; Lucotte *et al.* 1999) and can contribute to increased mercury levels in biota in such remote locations. In addition to the increasing atmospheric deposition to Lake Victoria, increasing eutrophication and hypoxia in the lake may favour methylation and that potentially can elevate Hg concentrations in fish.

### **The current state and nature of metal contamination in Lake Victoria**

In a review of metal pollution in Africa, Nriagu (1992) pointed out that toxic metal concentrations in many ecosystems of Africa are reaching exceptionally high levels. The major cause was contaminated dusts in the air of overcrowded cities. In addition, Lead contamination in water from automobiles and cottage industries (Nriagu, 1992) presents a health hazard to an estimated 15-30% of the infants in urban areas and could be indicative of an associated mercury problem.

In spite of the great importance of fish to the diet and economy of a large part of the local population, relatively few studies have been conducted on metal (mercury) contamination in fish tissue or aquatic environment of the Uganda part of Lake Victoria basin. Campbell *et al.* (2003b) have presented an extensive review of mercury in Lake Victoria and its implications for human and ecosystem health. Total Hg concentrations are higher in recently deposited sediments than earlier in the last century (Figure 2) and consequently, it might be expected that Hg levels are now higher in the fish tissues than historically, but there are no direct observations to support such a conclusion. The increase in total Hg deposited in lake sediments may be attributed to several possible changes including biomass burning, increased soil erosion from the catchment, recent flooding events and continued high water levels post-1961 could increase mobility of the Hg previously sequestered in soil and lake sediments (Bodaly *et al.* 1984; Hecky *et al.* 1992). Sediment and soil total Hg concentrations were within international guidelines and comparable to those in northern latitudes, but lower than those in the Amazon basin. Total Hg concentrations in water were below Canadian drinking water guidelines but were elevated relative to those in the northern Great Lakes. As usually found in aquatic ecosystems around the globe, in Lake Victoria methyl mercury ( $\text{HgCH}_3^+$ ) bio-accumulates and biomagnifies up the food chain. Additionally Ikingura and Akagi (1996) monitored fish and human exposure to Hg near the Lake Victoria gold fields in Tanzania. They found low Hg concentrations in fish (1.8 to 16.9 ng Hg/g, mean 7.0 ng Hg/g), and concluded that gold mining had not significantly increased methyl mercury concentrations in the lake environment but large amounts of Hg had been mobilized into the atmosphere by artisanal mining. Thus, despite evidence from sediment cores that deposition of Hg into Lake Victoria had increased over the last century (Campbell *et al.* 2003a), and that current concentrations of total Hg in Lake Victoria water are higher than in North American Great Lakes, methyl Hg concentrations in biota are much lower than in the North American Lakes and, in fact, pose little risk for human consumption.

Ramal *et al.* (2003) and Campbell *et al.* (2003c; 2004) studied the mercury concentrations in water, sediment and biota in Thruston Bay, Napoleon gulf and Isanga Rivers near Mwanza gulf of Lake Victoria. Lake Victoria Nile perch had higher total Hg concentrations (293-812 ng Hg/g dry weight) than other fish (35-110 ng Hg/g dry weight).

Mercury concentrations in Nile perch were similar to those of commercial fish in North American Great Lakes (140-320 ng/g) except Lake Michigan (Bernier *et al.* 1995) and were below the WHO (200 ng/g) and international (500 ng/g) marketing limits. In a separate study by the Fisheries Department, Uganda, mercury concentrations in fish fillet from Lake Victoria ranged from 33 to 92 ng/g, mean 61.8 ng/g (Fisheries Department Unpubl. Report, 2000). With the exception of large Nile perch > 5 kg, which are now rare and not acceptable to the export fishery, the Hg levels in the Lake Victoria fishery posed no health risks to the local population or to the export market (Mason and Sullivan, 1997; Campbell *et al.*, 2003b; Figure 3, 4).

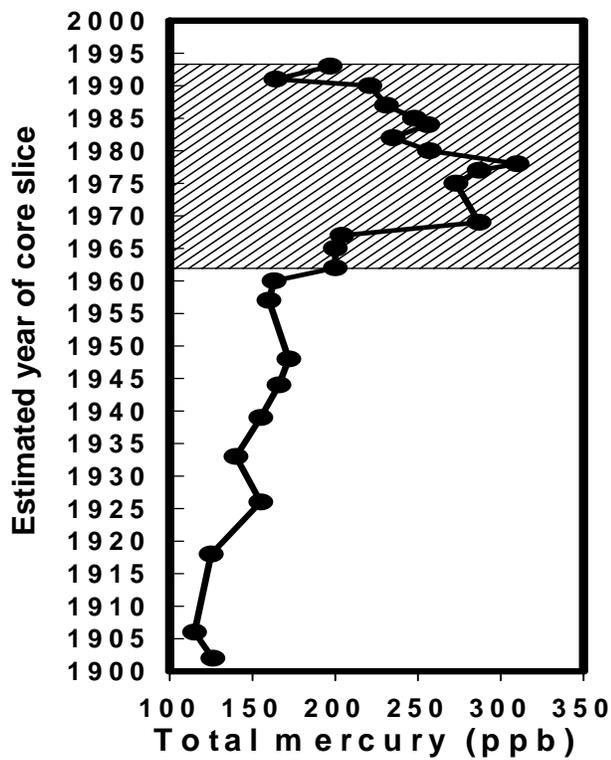


Figure 10.3 Mercury concentrations from a core taken from Itome Channel by P. Ramlal. Shaded area indicates when mercury concentrations increased after 1960. There is a decline in mercury after 1980, but concentrations are still higher than before 1960.

In a study of the variations in trace metal concentrations of major rivers of the Kenyan Lake Victoria basin, Mwamburi (2003) reported high Mn, Zn and Cr levels in the surface water and sediments of River Kasat that receives sewage input from Kisumu sewage treatment plant.

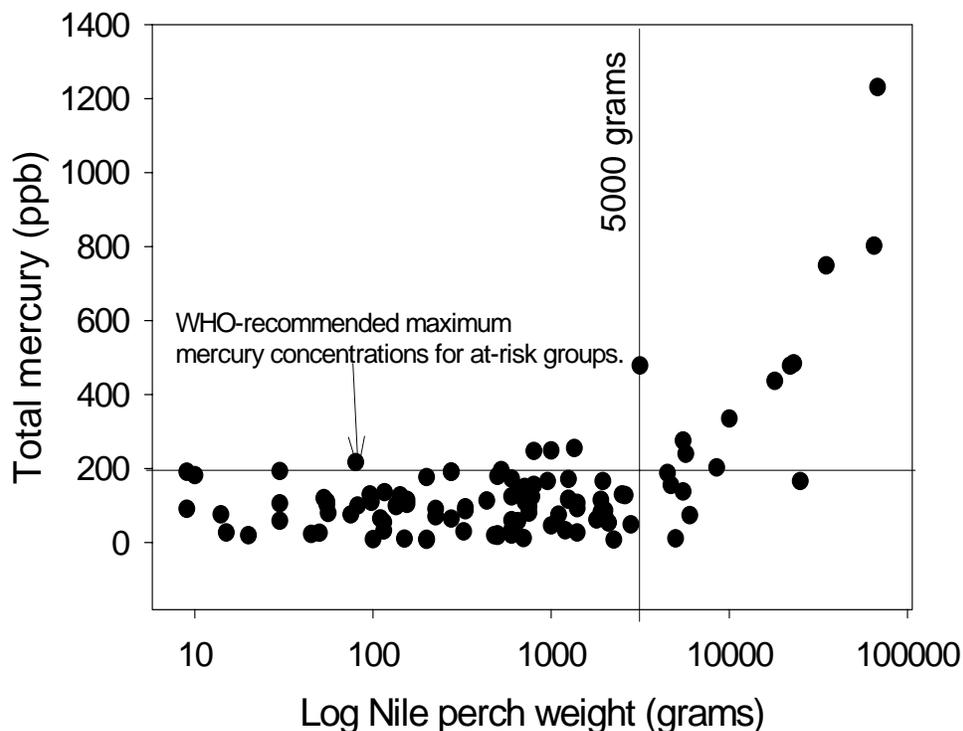


FIG. 4. Mercury concentrations in Nile perch from Ugandan, Kenyan and Tanzanian waters plotted against their weight. The data was compiled from six different studies. It shows that when Nile perch reaches 5000 grams, their mercury concentrations begin to exceed the World Health recommended guidelines for at-risk groups including pregnant women and young children under 15 years.

This pollution was attributed to both non-point (lithological) and point (municipal and industrial) inputs sources arising from waste disposal but the fate of these metal compounds within Lake Victoria is unknown. However, concentrations in offshore locations of all metals were low and below WHO drinking water guidelines. Only in nearshore locations and near tributary sources are the metal concentrations likely to pose a problem for aquatic organisms or for drinking water use.

### Land management implications

Much of the mercury in water and the atmosphere arise from land-based activities such as biomass burning and soil erosion. Burning volatilises mercury, which is then deposited into water, thereby contaminating the food chain. In addition, mining activities such as gold mining, release

mercury into the atmosphere. Although recent studies have shown mercury levels in water, fish and sediments were comparable to, or even lower than, other international water bodies, measures should be put in place to minimise land-based activities that contribute to mercury volatilisation, such as biomass burning. Enforcement of bylaws against bush burning, coupled with scaling up of better land management practices to minimise soil erosion is therefore called for. In addition, mining activities should ensure better environmentally-friendly processes for disposing/managing mercury fumes (a by-product of gold recovery processes). This could be enforced through regular licensing and monitoring of industrial (gold) processors for compliance. Eutrophication can also cause anoxia in the deeper waters of Lake Victoria, and this can alter the biogeochemical cycling of many of the toxic metals. Better land management leading to reduced nutrient loss from the land and restoring natural nutrient loading rates, especially for phosphorus, will reduce mobilization of many of the toxic metals.

## **CONCLUSIONS AND RECOMMENDATIONS**

Presence of banned organochlorinated pesticides such as DDT in the Lake Victoria catchment, pose a serious environmental risk to the population. Bans on agricultural use of organochlorine pesticides should be enforced to protect applicators, the aquatic environment and especially the valuable export fishery. Use of 'restricted chemicals' by incompetent users and the chances for adulteration of some of the chemicals pose concern over improper use and management of many chemicals, with serious environmental consequences. More trained applicators are required to ensure appropriate use of registered pesticides, and farmers should continue to be targeted for dissemination of information on best practices and uses of agrochemicals.

The elevated metal concentrations (Mn, Zn and Cr) detected in some rivers have been related to industrial activities or runoffs from urban areas and call for improved catchment management including controlled industrial and municipal waste disposal to minimise metal pollution. More stringent enforcement measures and regular monitoring should be put in place to control disposal of industrial waste material especially where Cd, Pb and Hg may be components of the wastes, coupled with better municipal waste management. Open burning of unsorted trash can lead to undesirable exposure to toxic fumes.

Land-based activities such as de-vegetation and biomass burning contribute much of the metal (e.g. mercury) contamination. Efforts to promote better land management activities to control biomass burning, soil erosion and atmospheric pollution should be ensured. Physical planning for better utilisation of land resources, especially in the identified erosion 'pollution hot spots' within the catchment, should be emphasised.

More studies and monitoring of pesticide and metal contamination in the atmosphere, water, sediments, flora and fauna should be carried out. Capacity (human, equipment) should be built for carrying out such studies.

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