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Polychlorinated biphenyls and hexachlorocyclohexanes in sediments and fish species from the Napoleon Gulf of Lake Victoria, Uganda

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HIGHLIGHTS

- High concentrations of PCBs were found at locations near Jinja Municipality.
- The PCB and HCH levels were low to moderate compared to other locations worldwide.
- The fish from the Napoleon Gulf was fit for consumption in regard to PCBs and HCHs.
- The ratios of α-/γ-HCH were low suggesting past input of lindane.

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ABSTRACT

Polychlorinated biphenyls (PCBs) and hexachlorocyclohexanes (HCHs) were analyzed in surface sediments (<30 cm depth) and two fish species: Nile perch (*Lates niloticus*) and Nile tilapia (*Oreochromis niloticus*). The samples were collected from the Napoleon Gulf on the northern shore of Lake Victoria. The analysis was done using a gas chromatograph (GC) coupled to a high resolution mass spectrometer for PCBs and a GC equipped with an electron capture detector for HCHs. Total (Σ) PCBs in the muscles of fish varied widely with mean values ranging from 41 to 670 pg g^{-1} lipid weight (lw). The PCB levels in *L. niloticus* were significantly greater than those in *O. niloticus*. The large variability observed in the data was attributed to differences in feeding habits and trophic levels. While *O. niloticus* is a filter-eating fish species feeding mainly on phytoplankton and zooplankton, *L. niloticus* have predatory feeding behaviors and prefer a diet of live fish and, therefore, are more prone to bio-accumulate contaminants. The mean PCB concentrations in the sediments varied from 362 to 848 pg g^{-1} dry weight. Variations in PCB levels were observed from one study site to another, this was attributed to the nature and particle size of the sediments. HCH isomers were detected in fish at mean concentrations of up to 45,900 pg g^{-1} lw. The PCB and HCH concentrations were lower than those from previous studies elsewhere in literature and were below the maximum residue limits set by the European Commission and FAO/WHO Codex Alimentarius Commission, implying that the fish was fit for human consumption.

1. Introduction

Lake Victoria is the world's second largest freshwater lake after Lake Superior in North America. Economically millions of people depend on the lake as a source of drinking water and fishing as a principal source of proteins to the local diet. The lake's fisheries contribute an annual foreign income of USD $124 million to Uganda's economy constituting the third foreign earner, after coffee and flowers (MAAIF, 2010). In recent years the lake is increasingly experiencing pollution from human and industrial wastes. The possible pollutants reaching the lake could be polychlorinated biphenyls (PCBs) and hexachlorocyclohexanes (HCHs). PCBs are synthetic organic compounds that were widely used in electric transformers, capacitors, printers and ink paints in the 1960s (Breivik et al., 2002, 2004). PCBs can still be formed as unintentional byproducts of waste incineration and industrial processes

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(Liu et al., 2009). However, concerns about their persistent and toxic nature led to their ban throughout the world in the late 1970s (Breivik et al., 2007). Technical HCH was widely used in Uganda and other parts of the world as an insecticide on fruits and vegetables in the 1980s (Ejobi et al., 1996; Lopez et al., 2012). The chemical was also banned worldwide in the 1990s because it is highly toxic (Li, 1999). Although, the use of PCBs and HCHs was stopped, their impacts on the environment cannot be neglected.

These pollutants reach water bodies via run-off and/or atmospheric transport. In aquatic ecosystems, small amounts of PCBs and HCHs may be re-dissolved at the water–sediment interface, but mostly tend to partition into sediments and suspended particles (Horzempa and Ditoro, 1983; Eisenreich et al., 1989). The chemicals have the potential to bioaccumulate across the food chain, building up in top predators through consumption of contaminated biota (Bjermo et al., 2013; Frouin et al., 2013). The fish at the top of the aquatic food chain are most likely to be affected by exposure to such pollutants (Bervoets and Blust, 2003; Wang et al., 2011). Different species of fish occupy different habitats in the same ecosystem and have different feeding behaviors. As a result, they are used as a good proxy to assess the influence of the environment and biological factors concerning the bioaccumulation of pollutants (Hu et al., 2009; Sullam et al., 2012). Understanding the primary factors influencing bioaccumulation of those compounds in fish from aquatic ecosystems is critical in predicting and assessing risks to upper-trophic level consumers including humans. Although, the levels of dioxin-like PCBs (mono-*ortho* and non-*ortho* PCBs) have recently been reported in the fish (Ssebugere et al., 2013a) and sediments (Ssebugere et al., 2013b) from the Napoleon Gulf, our survey of literature shows no data concerning HCHs and indicator PCBs. The study was aimed at obtaining preliminary information on the occurrence of HCHs and indicator PCBs in sediments and fish from the Napoleon Gulf. The resulting data will be used as a benchmark to compare the concentrations of the contaminants over time.

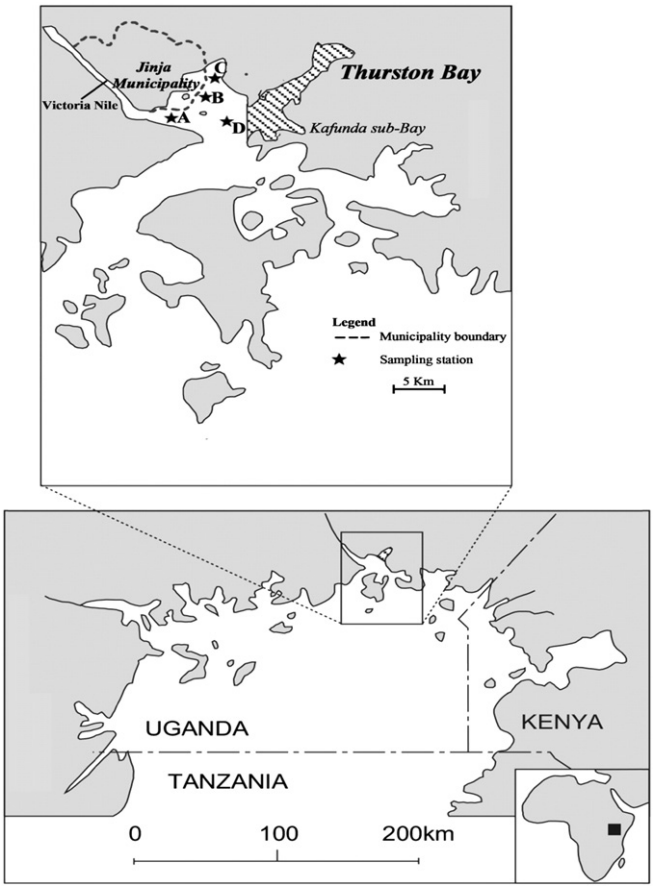

Fig. 1. Map showing the study stations.
Adapted from Campbell et al. (2004).

2. Materials and methods

2.1. Study area

The study area was the Napoleon Gulf which is located on the northern shoreline of Lake Victoria (0° 24′ 34″ N, 33° 14′ 50″ E). It is located south east of Jinja Municipality and covers an area of about 200 km^2. The Gulf supports approximately half a million inhabitants; however in recent years it has been subjected to strong anthropogenic pressures. The major pollution sources are untreated wastewater from sewage systems, industrial plants, waste oil from parking lots and car repair garages. The industrial plants in the vicinity of the Gulf include a water treatment plant and a copper smelting plant. In addition, catchment wetlands which previously played the vital role of tertiary purification of effluent before discharging it into the Gulf have long been encroached on for settlement and degraded.

2.2. Sampling

A total of 24 surface sediments (<30 cm depth) were collected in March, 2011 from the Napoleon Gulf using a sediment corer at four stations: A, B, C and D (Fig. 1). Within each station, 6 sediment samples were randomly taken at distances of approximately 200 m from one another. The number of collected sediment samples was dictated by the high cost of analysis of PCBs. A total of 96 fish (12 of the same species, summing up to 24 fish per station) were also collected from the four stations using gill nets. The fish weights and lengths were measured, and they varied from 520 to 2045 g and 34 to 60 cm, respectively. 10 g of muscle tissues from every four fish of the same species, with approximately the same length and weight were separately pooled. The pooled tissues were homogenized into composite samples using a blender. The fish were pooled to reduce the cost of analysis that would be incurred on the bulky individual samples. The sediments and homogenized fish samples were transferred into acetone rinsed glass bottles and kept at −20 °C prior to extraction.

2.3. Chemical analysis of polychlorinated biphenyls

The analytical procedures used in this study are described in detail by Ssebugere et al. (2013a). Briefly, samples were allowed to thaw and 10 g of each was separately spiked with ^{13}C-labeled PCB surrogate standards (US EPA defined 68A-LCS). The spiked tissues were then mixed with hydromatrix™ (Varian) to remove any moisture. Extraction was performed on an accelerated solvent extraction device (Dionex ASE 200), using a 3:1 *v*/*v* mixture of *n*-hexane/acetone, and the resulting extracts were concentrated to 2 mL using a rotary evaporator. The concentrated extract was divided into two subsamples for the fish (0.3 and 1.7 mL). The 0.3 mL was used for lipid determination by gravimetric methods while the 1.7 mL was passed through a drying funnel of anhydrous sodium sulfate and eluted with 100 mL of *n*-hexane. The resultant mixture was purified using two successive chromatographic steps.

The first clean-up step involved use of a multilayer column containing from bottom to top: 2 g silica gel, 5 g of 33% silica gel-sodium hydroxide, 2 g silica gel, 5 g of 44% silica gel-sulfuric acid, 10 g of 22% silica gel-sulfuric acid and 5 g anhydrous sodium sulfate. The column was pre-washed with 60 mL of *n*-hexane before the extract was added and this was followed by elution with 60 mL of *n*-hexane. The eluate was concentrated using a rotary evaporator and transferred to a carbon column. It was then eluted with 100 mL of *n*-hexane (this was the second clean-up step). The resulting eluate was reduced to <1 mL using a stream of nitrogen. An aliquot of 20 μL nonane and the eluate were quantitatively transferred into vials. The mixture was