Profiling pesticide concentrations for sustainable lake-use management in Lake Victoria Basin, Kenya: Are they within the recommended limits?

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Abstract

It is crucial to have a coordinated mapping of banned pesticide contaminants in aquatic systems to assess the risks associated with water and fish consumption. The objective of this study was to evaluate pesticide residue levels in Lake Victoria, Kenya, with respect to global thresholds using water and sediment samples collected from representative sites (Kisumu, Awach, Oluch, Mbita, Sondu, and Yala) between 2013 and 2018. The solvent-phase extraction (SPE) method was used to extract the samples. The results of the pesticide distribution analysis in natural water indicated higher mean HCH isomer residues in Winam Gulf compared to open waters. Since water is a vital resource for humans and fish, these concentrations are of particular concern. The highest observed concentration in sediment samples was the mean *p,p'*-DDT (58.80 ± 3.618 µg kg^{-1}). Organochlorine residues in water samples were below the recommended limits set by the World Health Organization (WHO), but sediment samples exceeded these limits. As a result, there is a continuous need for regular monitoring of both local and regional data from point and non-point sources to ensure human and environmental health is safeguarded and to implement mitigation measures.

Keywords: Winam Gulf, pesticides residues, organochlorines, WHO guidelines

Introduction

A pesticide is defined as a substance or a combination of substances designed to prevent, destroy, repel, or alleviate any type of pest, which may include insects, mites, nematodes, weeds, and rats, among others. This category encompasses insecticides, herbicides, fungicides, and a wide range of other compounds used for pest control (US EPA, 2007). The history of pesticides at a global level can be categorized into three distinct phases. The first phase occurred before the 1870s and involved the use of natural pesticides such as sulphur in ancient Greece to manage pests. The second phase took place between the 1870s and 1945 and was characterized by the use of inorganic synthetic pesticides as well as natural substances. The third and most recent phase started after 1945 and has been defined by the use of organic synthetic pesticides known as chemical pesticides, including compounds like DDT, 2,4-D, and later HCH, such as α-HCH, δ-HCH and cyclodienes including endosulfans and methoxychlor (Wasswa *et al.*, 2011; Zhang *et al.*, 2011).

The worldwide consumption structure of pesticides has undergone significant changes since the 1960s. The proportion of herbicides in pesticide consumption increased rapidly, from 20% in 1960 to 48% in 2005 while the proportion of consumption of insecticides and fungicides/bactericides declined despite the increase in their sales (Mbabazi, 1998; Wheelock *et al.*, 2008). The application of chemical pesticides, in particular, organic synthesized pesticides i.e. herbicides greatly protects and facilitates agricultural productivity leading to enhanced agri-

cultural intensification and productivity (Wheelock *et al.,* 2008; Nyaundi *et al.,* 2020). Without pesticide application, the loss of fruits, vegetables, and cereals from pest injury would reach 78%, 54% and 32% worldwide, respectively (Cai, 2008). Crop loss from pests declined to 35% from 42% when pesticides were used (Pimentel, 2009; Dhaliwal *et al.,* 2010). Over the period from 2007 to 2008, herbicides ranked first in three major categories of pesticides (insecticides, fungicides, bactericides, and herbicides). Fungicides and bactericides increased rapidly and were ranked second. Europe is now the largest pesticide consumer in the world, seconded by Asia. In terms of countries, China, the United States, France, Brazil, and Japan are the largest pesticide producers, consumers and traders in the world (US EPA, 2007; Pimentel, 2009; Dhaliwal *et al.,* 2010). Most pesticides are not spontaneously generated and are highly toxic to humans and the environment and their degraded products flow and accumulate freely in the atmosphere, soils, and rivers (WHO, 2019).

Organochlorine pesticides (OCPs) are parts of persistent organic pollutants (POPs), which include HCH, DDT, aldrin, dieldrin, endrin, chlordane, heptachlor, toxaphene, HCB, etc. POPs are a group of compounds that remain intact in the environment for long periods, become widely distributed in nature and accumulate in the fatty tissue of humans and wildlife. Exposure to POPs can lead to serious health effects including certain cancers, birth defects, dysfunctional immune and reproductive systems, greater susceptibility to disease and even diminished intelligence (WHO, 2019). To substitute these persistent organochlorine pesticides, agricultural sectors have shifted towards organophosphate pesticides. However, organophosphate pesticides are generally much more toxic to vertebrates compared to other classes of insecticides even though they rapidly degrade in the environment (Chambers *et al.*, 2001; Gupta and Doss, 2022).

According to the "Stockholm Convention on Persistent Organic Pollutants", nine in twelve POPs are organochloride pesticides and there are more than 26 million human pesticide poisonings with about 220,000 deaths per year (Peter *et al.*, 2002; Richter, 2002; Gunnell *et al.*, 2007). In general, detailed and continuous data are still lacking on the impact of pesticides on human health and the environment (Kubiak-Hardiman *et al.*, 2022). Three major areas of pesticide use in Africa have been and remain agriculture, livestock development, and human health (Wandiga, 2001). Pesticide consumption in Africa accounts for about 3% of global use, with South Africa making up about 2% of pesticide consumption in the world (FAO, 2022).

Lake Victoria is an ecosystem of global concern since it is the largest tropical and the second-largest freshwater lake in the world with a surface area of 68,000 km^2. It is shared by Uganda (43%), Tanzania (51%) and Kenya (6%) (Njiru *et al.,* 2012). In recent years, the ecological health of the Lake is being threatened by rapid urbanization and industrialization. This development, coupled with a population of over 60 million people (Nyamweya *et al.*, 2020) in its catchment area has resulted in increased anthropogenic activities that exert pressure on the lake ecosystem (Banadda *et al.*, 2009; Wasswa *et al.*, 2011). In addition, riparian wetlands which previously played a vital role in tertiary purification of effluent before discharge into the lake have long been encroached on for settlement (Wasswa *et al.*, 2011). Pollution to the environment through pesticide accumulation is one such example of increased anthropogenic influence.

In Kenya, organochlorine pesticides have been in use in farming and livestock since the 1940s (Aucha, 2017). Lindane was the first organochlorine pesticide introduced in 1949 for the control of ticks. This was followed by the import of toxaphene in 1950, DDT in 1956, and dieldrin in 1961 (Abong'o *et al.*, 2014). They were imported for sole use by white farmers for livestock rearing (Aucha, 2017). DDT was banned in Kenya in 1985, while aldrin and dieldrin were banned in 1992 (PCPB, 2022). Organochlorine pesticides which remained officially in use in Kenya are endosulfan, alpha, gamma-BHC, and alachlor (Madadi

et al., 2006; Aucha, 2017). Because of its threats to human health and the environment, a global ban on the manufacture and use of endosulfan was negotiated under the Stockholm Convention in April 2011. The ban took effect in mid-2012, with certain uses exempted for five additional years. Most of the pesticides used in the Nyando catchment area are organophosphate and are moderately hazardous, but some individual farmers still use banned or restricted organochlorine pesticides (Musa *et al.*, 2011; Abong'o *et al.,* 2014; Nyaundi *et al.*, 2020).

Incidences of pesticide poisoning of fish were highlighted by the press in May 1999. The fish was purportedly harvested from the lake by using endosulfan; an organochloride insecticide. This resulted in a ban by the European Union (EU) on all fish imports from Lake Victoria (LVEMP and MoALD, 1999), greatly affecting the economies of the three riparian countries. The total loss of income due to the ban was estimated to be more than US $ 300 million (LVEMP 2003). There are individual reports on pesticide concentrations in fish (Henry and Kishimba, 2006), water (Getenga *et al.*, 2004), soil and sediments (Abong'o, 2009; Osoro *et al.*, 2016) and from parts of the lake.

River Nyando, located in Western Kenya, is identified as the most contaminated drainage basin on the Kenyan side of Lake Victoria by Shepherd *et al.* (2000). The river system traverses agricultural and industrial zones, making it a recipient of various pollutants from tea, coffee, lime, and sugar factories that utilize a diverse range of pesticides. Additionally, it exhibits the highest slope and sediment transport rate among all the rivers that flow into Lake Victoria. The unfavourable land-use management practices and excessive use of agrochemicals have led to a high influx of nutrients and sediments, negatively affecting the river and Lake Victoria ecosystems (Peters and Meybeck, 2000).

There is a tremendous need for coordinated and accessible mapping of pesticides and micro-contaminant concentrations in the Lake Victoria Basin to focus on the current pollution status as well as ensure that the fish ban by the EU in 1999 does not recur. Thus the present study sought to provide the status of pesticide concentrations and their impact in Lake Victoria, Kenya, in order to advice on the lake use and fishery industry in relation to the set limits.

Materials and Methods

Study area

The study area constituted sites outside and in Winam Gulf, a shallow inlet connected to the main lake by the deep, narrow Rusinga Channel, about 4 km wide (Fig. 1). The main lake is connected by a narrow channel which is a region of active interchange involving the main lake and the gulf, with an average depth of 8 m, a width of about 25 km and extends for 64 km from Kisumu City to the channel. The gulf receives an average annual river discharge of about 2.4 km^3, hence draining rich intensive farming areas, municipalities, and manufacturing areas, all of which supply heavy loads of suspended sediments and nutrients into the gulf (Njiru *et al.*, 2012).

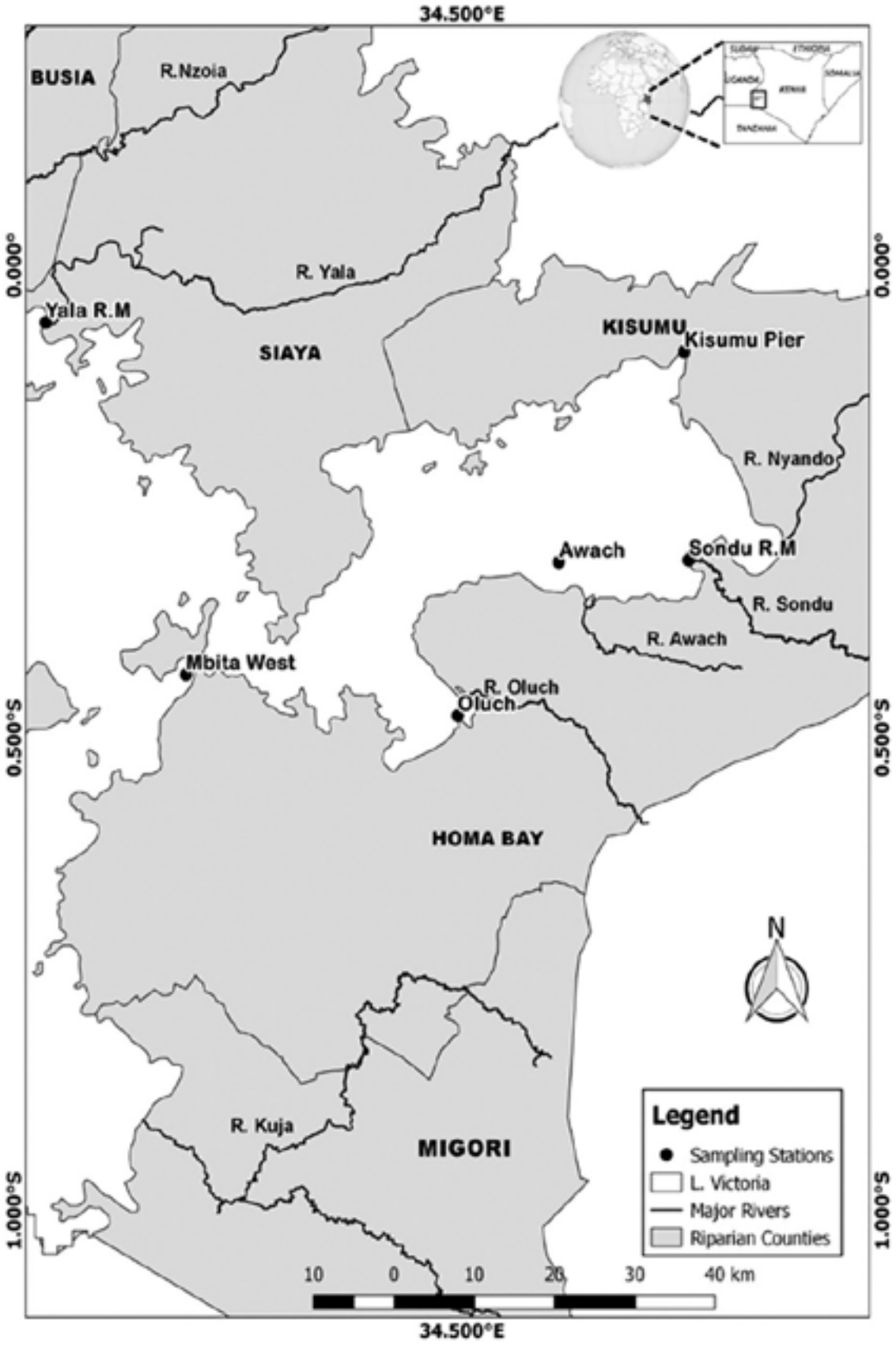

Figure 1. Lake Victoria, Kenya showing the various sites sampled during the study (Source: Authors).

Average rainfall in the eastern side of the catchment is seasonal, about 1,550 mm yr^{-1}, with two maxima. The main rain season occurs between March and May, with an intermittent short rain period (September-November). The minimum monthly air temperatures range from 16.0°C - 18.0°C while the maximum temperatures lie between 27.5°C and 30.0°C. The winds occur in a south-westerly direction and are strongest in the afternoons. The representative sampling sites which included the Kisumu river mouth, Awach river mouth, Oluch river mouth, Mbita river mouth, Sondu river mouth and Yala river mouth (Fig. 1) were chosen since they act as a confluence of anthropogenic discharges.

Sampling regime and sample collection

Sampling and analyses of pesticides were undertaken as per standard methods as shown in various literature (Getenga *et al.*, 2004; Henry and Kishimba, 2006; Abong'o, 2009; Osoro *et al.*, 2016). Figure 2 shows the schematic representation of the procedure undertaken to relate pesticide field data to the set limits. Sampling stations were marked using a GPS (Magellan Global Positioning System, 315 Meridian). Water and sediment pesticide data were taken from six sampling sites on a quarterly basis, between March 2013 and December 2018 in the Winam Gulf, Lake Victoria to coincide with the long rain (April-May), the dry (July) and the short rain (September) seasons. Water samples, taken in composites, were obtained using the grab method (APHA, 2012), into 2.5 L amber glass bottles that had been pre-washed with distilled water and dried.

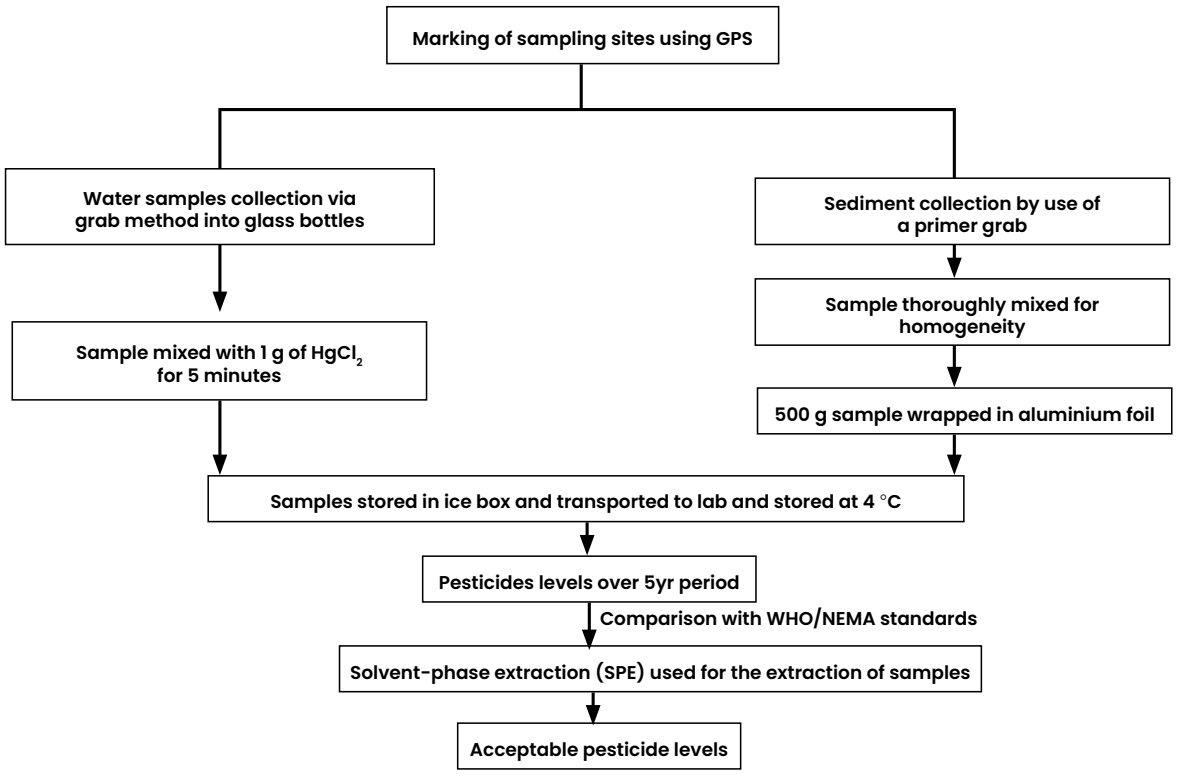

Figure 2. Sampling and sampling preparation framework towards the mapping of pesticide concentrations in Lake Victoria, Kenya.

After the collection of the water samples, 1.0 g of mercuric chloride was thoroughly mixed with the sample for 5 minutes. This was used as a treatment option to avoid the degradation of pesticides by microorganisms. Sediment samples were also obtained from the same sampling sites using a Punner grab and thoroughly mixed to homogenize before a 500 g aliquot was carefully separated and wrapped in aluminium foil. Before extraction, all the samples were temporarily stored in an icebox with wet ice, transported to the laboratory and kept in a standard fridge at 4°C. Solvent-phase extraction (SPE) method was used in the extraction of all the samples.

Sample extraction, clean-up and analysis

The method described is a modified version of the EPA Method 3545 for the extraction of organic compounds from water, soil, and sediment samples as described by Houck (2000) and Krieger (2001). Used glassware was soaked in detergent for 24 hours, washed and rinsed in distilled water before being oven-dried at 100°C for 24 hours. Solvent-phase extraction (SPE) method was used in the extraction of water samples. Subsequently, 50 ml of 0.2 M dipotassium hydrogen phosphate buffer was added to a water sample of 2.0 L and later transferred into a separatory funnel. Its pH was adjusted to 7.0 by adding drops of 0.1 M sodium hydroxide and 0.1 M HCl solutions to neutralize the sample. About 100 g sodium chloride was then added to salt out the pesticides from the aqueous phase, while slowly releasing pressure, 60 mL triple distilled dichloromethane (DCM) was added to this solution and shaken for two minutes.

Separation of the phases was achieved after allowing the sample to settle for 30 minutes. A 250 mL Erlenmeyer flask was then used to collect the organic layer and extraction was repeated twice using 60 mL portions of dichloromethane. After storage in a refrigerator at 4°C, the extracts were combined and cleaned by passing them through an Al_2O_3 chromatographic column topped with anhydrous sodium sulphate. Pesticide residues were sequentially eluted with 175 mL n-hexane. It was necessary to concentrate the elutes to 1 mL using a rotary evaporator at 40°C, and to reconstitute them in 0.5 mL HPLC grade isooctane for GC analyses.

Before mixing, the sediment samples were allowed to thaw for 4 hours in the laboratory. The EPA method 3540 Soxhlet extraction of sediments was then applied before transferring the sediment samples to the Soxhlet thimble. Triplicates of 20 g samples were dried overnight using activated anhydrous sodium sulphate (Na_2SO_4), then extracted with 200 mL of hexane to acetone (3:1 v/v) in 250 mL round-bottomed flasks for a minimum of 16 hours.

After storage in a refrigerator at 4°C, the extracts were combined and cleaned by passing them through an Al_2O_3 chromatographic column topped with anhydrous sodium sulphate. The elutes were concentrated to 1 mL using a rotary evaporator at 40°C, and reconstituted in 0.5 mL HPLC grade isooctane for GC analyses. The final samples were analyzed by a Varian Chrompack CP-3800 GC equipped with an electron capture detector, under the conditions specified. The following organochlorine pesticide residues were identified: α-HCH, β-HCH, γ-HCH, δ-HCH, *p,p'*- DDD, *p,p'*-DDE, *p,p'*-DDT, aldrin, endrin, dieldrin, endrin aldehyde, endosulfan I, endosulfan II, endosulfan sulphate, heptachlor, heptachlor epoxide, and methoxychlor.

Quality control

Replicate sampling was employed as well as extraction and analysis of the samples collected for quality control and assurance. The detection limit of each pesticide investigated was handled using international standards and pure distilled water as blanks. Spiking of water samples was carried out using 2 L of distilled water and sediments busing 20 g of anhydrous Na_2SO_4 to a sample concentration of 0.1 $\mu g\ L^{-1}$.

Identification and quantification of pesticide residues in the samples obtained were done by the use of a high-quality pesticide standards mixture of over 99% purity. The pesticide standards were obtained from Dr. Ehrenstorfer GmbH, (Augsburg, Germany). Solvents such as dichloromethane (DCM), acetone, isooctane, and hexane were sourced from Fisher Scientific (USA). Other consumable chemicals such as hydrochloric acid (HCl), methanol (CH_3OH), sodium chloride (NaCl), aluminium oxide (Al_2O_3), sodium hydroxide (NaOH), copper (Cu) and anhydrous sodium sulphate (Na_2SO_4), all of analytical grade, were also obtained from Fisher Scientific (USA). General purpose reagents (GPR) were triple distilled in all-glass apparatus before use.

Data analysis

The data obtained were recorded in MS Excel sheets and subjected to analyses in R version 3.5.0 (R Core Team, 2014). The significance level was set at $p < 0.05$. The ranges and means

for the pesticides were obtained for comparison with the National Environment Management Authority (NEMA) and the World Health Organization (WHO) recommended guidelines.

Results and discussion

The study revealed a total of 17 different organochlorine pesticides (OCPs): α-HCH, β-HCH, γ-HCH, δ-HCH, *p,p'*- DDD, *p,p'*-DDE, *p,p'*-DDT, aldrin, endrin, dieldrin, endrin aldehyde, endosulfan I, endosulfan II, endosulfan sulfate, heptachlor, heptachlor epoxide, and methoxychlor, both in water and sediment samples over a period of five years. Organochlorine pesticide residues from six target sampling sites ranged from below detection limit (BDL) to detection level, indicating local input of the detected contaminants within the study area. NEMA and WHO pesticide threshold limits in Lake Victoria, Kenya, are listed in table 1. Concentrations from analyzed water and sediment samples produced a total of 17 different organochlorine pesticides (OCPs) identified during the study period (Table 2).

Table 1. Pesticide limits in water and sediments as recommended by NEMA and WHO (FAO and WHO, 2016).

Pesticide Name	NEMA (µg L^{-1})	WHO (µg L^{-1})
Aldrin	0.03	0.03
Endrin	NR	0.6
p,p'-DDT	2	1
Heptachlor	0.03	0.03
Heptachlor Epoxide	0.02	0.03
Endrin Aldehyde	NR	0.6
α-HCH	2	2
β-HCH	2	2
γ-HCH	2	2
δ-HCH	2	2
Endosulphan I	0.01	-
Dieldrin	0.25	0.03
Endosulphan II	0.01	-
Methoxychlor	20	20
Endosulphan sulphate	-	-
p,p'- DDD	-	1

Table 2. Overall mean pesticide residues for the period from 2013 to 2018 in Lake Victoria, Kenya in relation to WHO-recommended concentration limits.

Pesticide	Water (µg L^{-1})	Sediment (µg L^{-1})	WHO (µg L^{-1})
α-HCH	0.03	39.67	2
β-HCH	0.13	8.69	2
g-HCH	0.02	12.56	2
d-HCH	0.03	14.32	2
Heptachlor	0.13	25.81	0.03
Aldrin	0.06	21.45	0.25
Heptachlor Epoxide	0.08	15.93	0.02
Endosulphan I	0.01	36.99	0.01
p,p'-DDE	0.02	4.78	0.01
Endrin	0.02	12.58	0.01
Dieldrin	0.01	26.63	0.25
Endosulphan II	0.03	12.05	0.01
p,p'- DDD	0.04	8.76	0.01
Endrin Aldehyde	0.06	44.93	0.03
p,p'-DDT	0.21	58.80	1
Endosulphan sulphate	0.29	44.18	0.01
Methoxychlor	0.76	24.67	20

Exposure to methoxychlor, an insecticide, can occur when spraying deter insects such as mosquitoes, cockroaches and flies and is known to be toxic both to aquatic animals and humans. Additionally, methoxychlor can bio-accumulate in the tissues of these organisms. Mean results from this study indicated that methoxychlor residue levels ranked highest in water samples analyzed from the Kisumu Bay site (1.31 ± 0.002 µg L^{-1}), Mbita (1.13 ± 0.01 µg L^{-1}), Sondu Miriru (1.05 ± 0.005 µg L^{-1}) and Yala (0.79 ± 0.2 µg L^{-1}) and second highest in Oluch (0.13 ± 0.003 µg L^{-1}) and Awach (0.14 ± 0.002 µg L^{-1}) (Fig. 5). However, this was still well below WHO threshold levels of 20 µg L^{-1} in natural water (Fig. 3). Overall results obtained in all the target sites indicated that it recorded the highest score in sampled water, at a mean value of 0.76 ± 0.003 µg L^{-1}. This indicates that either methoxychlor is still being used on crops, livestock, and in animal feed or carried downstream via runoff. Once methoxychlor is deposited in the ground after its application on forests, food crops and animals, it adheres strongly to the soil. These soil particles are either blown by the wind or carried downstream as runoff (Rodríguez-Eugenio *et al.,* 2018).

Endosulfan sulphate in water samples was the highest in Awach (0.19 ± 0.01 µg L^{-1}), followed by Sondu Miriu (1.04 ± 0.002 µg L^{-1}) and Oluch (0.06 ± 0.001µg L^{-1}) (Figs. 3 & 5). Overall, endosulfan sulphate ranked second highest in analyzed water samples (0.29 ± 0.005 µg L^{-1}) and the third highest in sediment samples (44.18 ± 1.412 µg L^{-1}) within the period under study (Fig. 6). NEMA (2012) provides no guideline value for endosulfan sulphate since its occurrence in drinking water is documented to be at concentrations that don't arouse health concerns. Mean *p,p'*-DDT pesticide concentrations for water samples were the highest in Sondu Miriu (0.63 ± 0.004 µg L^{-1}) and lowest at Awach (0.08 ± 0.0001 µg L^{-1}) (Fig. 3). The concentrations were well below the WHO-recommended value of 1 µg L^{-1}. *p,p'*-DDT ranked first in sediment samples from Kisumu (92.01 ± 5.162 µg L^{-1}) and first in the overall concentrations of the sediment samples over a five-year span with 58.80 ± 2.013 µg L^{-1} (Table 2).

Cases of DDT use have been reported previously in vector-borne disease control efforts within

the Lake Victoria Basin, and it is known to survive in soils and air for up to 30 years. In addition, a study by Golfinopoulos *et al.* (2003) has shown that thunderstorms and rains could cause residual DDT to be carried in flush floods, ending up in the lacustrine ecosystems. A study carried out by M'Anampiu (2011) also revealed that the degradation of DDT and mirex in exposed fish was very slow compared to other pesticides and that there was very little excretion of the pesticide via urine and gills even after 48 hours of exposure and this can pose very serious public health concerns.

Analyzed bottom sediment samples showed methoxychlor pesticide residue levels with high mean concentrations which were above the WHO global recommended standards of 20 µg kg^{-1}. Kisumu Bay site recorded a high mean value of 82.07 ± 3.201 µg kg^{-1}, while 44.79 ± 1.271 µg kg^{-1} was recorded at the Oluch station and 115.59 ± 4.372 µg kg^{-1} in the Sondu Miriu sampling station (Figs. 4 & 6).

Mean endosulfan pesticide concentrations in bottom sediments was four times higher in the Awach sampling station (144.42 ± 1.072 µg kg^{-1}) as compared to the Sondu Miriu site (59.01 ± 3.102 µg kg^{-1}) (Figs. 4 & 6). However, its environmental impact on other organisms should be taken into consideration. Endosulfan sulphate has not been classified by NEMA as toxic since its quantities in natural water are much lower (NEMA, 2012). However, according to a study conducted by Shetty *et al.* (2000) on the biodegradation of cyclodiene insecticide endosulfan by *Mucor thermohyalospora,* it was reported that endosulfan, a parent compound, can be persistent and toxic to non-targeted organisms such as fish and should therefore be of environmental concern (Singh and Singh, 2011).

The concentration of DDT in water samples is considered more significant compared to its levels in the sediments due to its availability in the former for use by humans and fish. Results from this study, however, showed concentrations that were below the recommended limits by FAO/WHO compared to residue levels in sediments whose values were way above these globally recommended standards. The presence of DDT pesticides in analyzed sediment samples, although it had been banned from use decades ago in Kenya (1994), could probably be due to previous use in the catchment under study (Mbabazi, 1998; Getenga *et al.*, 2004; Nyaundi *et al.*, 2020) as it is known to bio-magnify and persist in the environment for a long period.

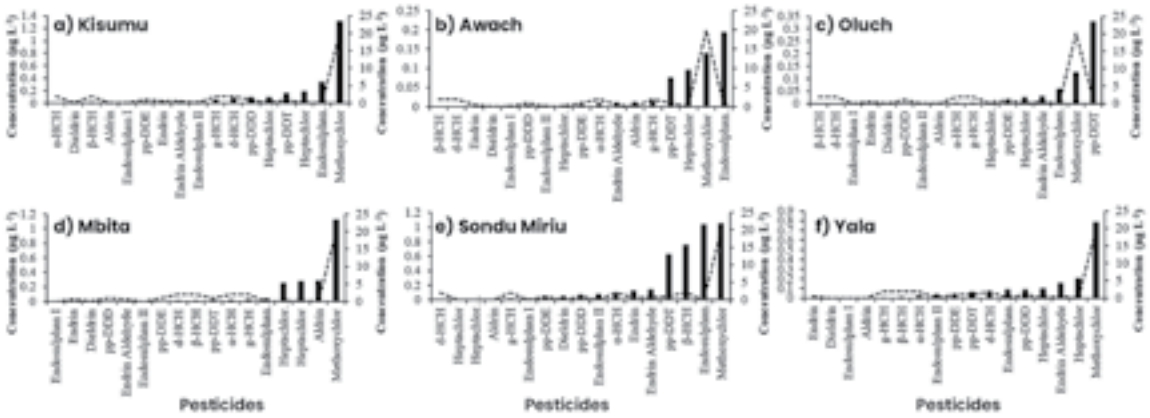

Figure 3. Organochlorine pesticide residue means in water samples from the selected study sites in Lake Victoria, Kenya over a five-year period from 2013 to 2018. The dotted line represents WHO recommended limits.

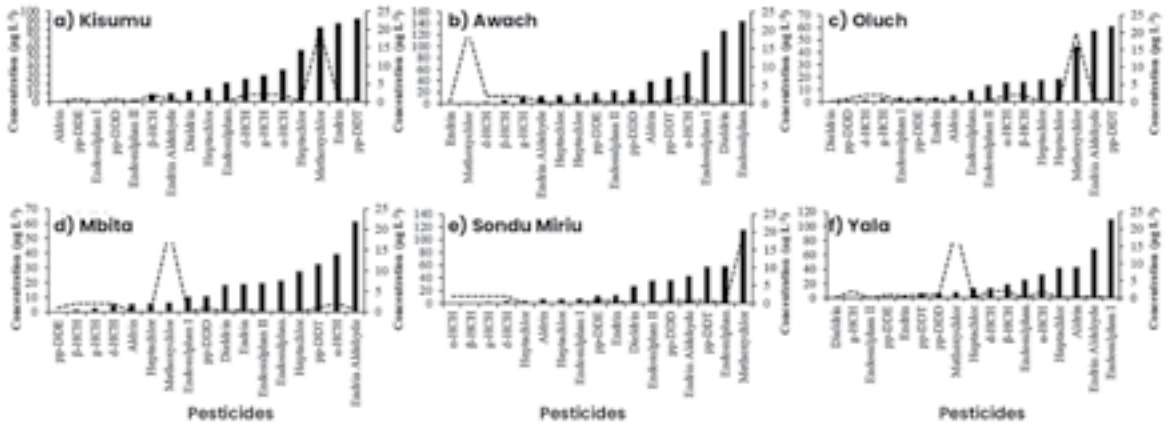

Figure 4. Organochlorine pesticide residue means in sediment samples from the selected study sites in Lake Victoria, Kenya over a five-year period from 2013 to 2018. The dotted line represents WHO recommended limits.

Heptachlor pesticide and its oxidized product heptachlor epoxide were detected in water samples in insignificant spatial variations (p = 0.142). However, the Yala river mouth sampling station showed a mean value of heptachlor in sampled water at 0.21 ± 0.004 µg L^{-1} residue level whereas heptachlor epoxide recorded a mean value of 0.1 ± 0.001 µg L^{-1}. At the Mbita sampling site the values recorded for heptachlor were 0.27 ± 0.02 µg L^{-1} and 0.26 ± 0.006 µg L^{-1} for heptachlor epoxide while at the Kisumu station, the mean contamination levels recorded for heptachlor were 0.17 ± 0.002 µg L^{-1} and 0.1 ± 0.0001 µg L^{-1} for its degraded compound, heptachlor epoxide (Fig. 3).

Concentrations of the parent compound heptachlor and its dissipated compound heptachlor epoxide in sediment samples were detected at varying levels during the study. Mean residue levels were recorded as: 57.84 ± 2.016 µg kg^{-1} and 14.89 ± 1.732 µg kg^{-1} in Kisumu; 42.24 ± 3.005 µg kg^{-1} and 0.02 ± 0.001 µg kg^{-1} in Yala, 18.46 ± 0.8421 µg kg^{-1} and 17.85 ± 2.003 µg kg^{-1} in Oluch and 6.09 ± 0.005 µg kg^{-1} and 27.83 ± 2.021 µg kg^{-1} in Mbita for heptachlor and heptachlor epoxide pesticides in sediment samples, respectively (Fig. 4). The overall concentrations for the period under study were 0.13 ± 0.006 µg L^{-1} and 0.08 ± 0.0001 µg L^{-1} for heptachlor and heptachlor epoxide,

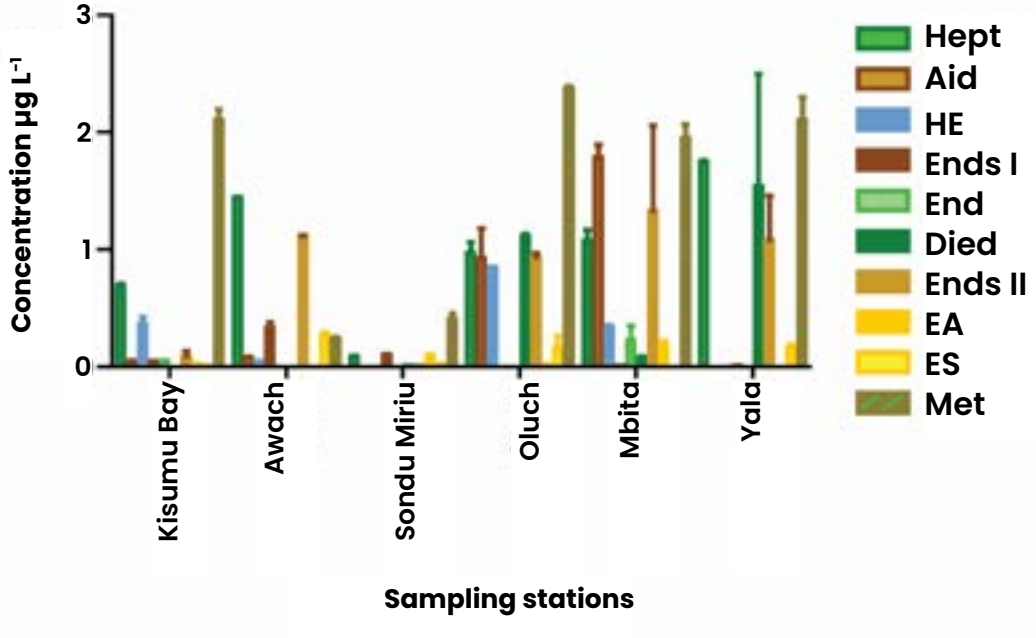

Figure 5. Generated pesticide levels in water obtained from the sampling stations during the study period.

respectively, in water samples and 25.81 ± 2.021 µg kg^{-1} and 15.93 ± 3.101 µg kg^{-1} heptachlor and heptachlor epoxide, respectively for sediment samples (Table 2).

The sample analysis results show that these concentrations were above the NEMA recommended value of 0.03 µg kg^{-1} for both heptachlor and heptachlor oxide in bottom sediment samples. The presence of heptachlor and its degradation product is an indication that heptachlor has been used in the area in recent times and is still currently in use. The higher concentration of heptachlor epoxide compared to heptachlor in Mbita shows that the rate of application was higher in the past than it is currently according to Abong'o *et al.* (2015), since this is a degraded compound from its parent compound. Heptachlor residues were detected probably due to its application as a household insecticide, termite control agent as well as an herbicide, in agricultural settings whereby it ended up being transported downstream as runoff. These levels should be of concern since heptachlor and heptachlor oxide have been reported by ATSDR to accumulate in fish, livestock and the body fat of humans and could still be detected up to three years after exposure (SRC, 2007). Prolonged exposure to these compounds can cause humans to experience dizziness, weakness, headache and feelings of 'prick and pin' on human skin (Hughes *et al.,* 2014).

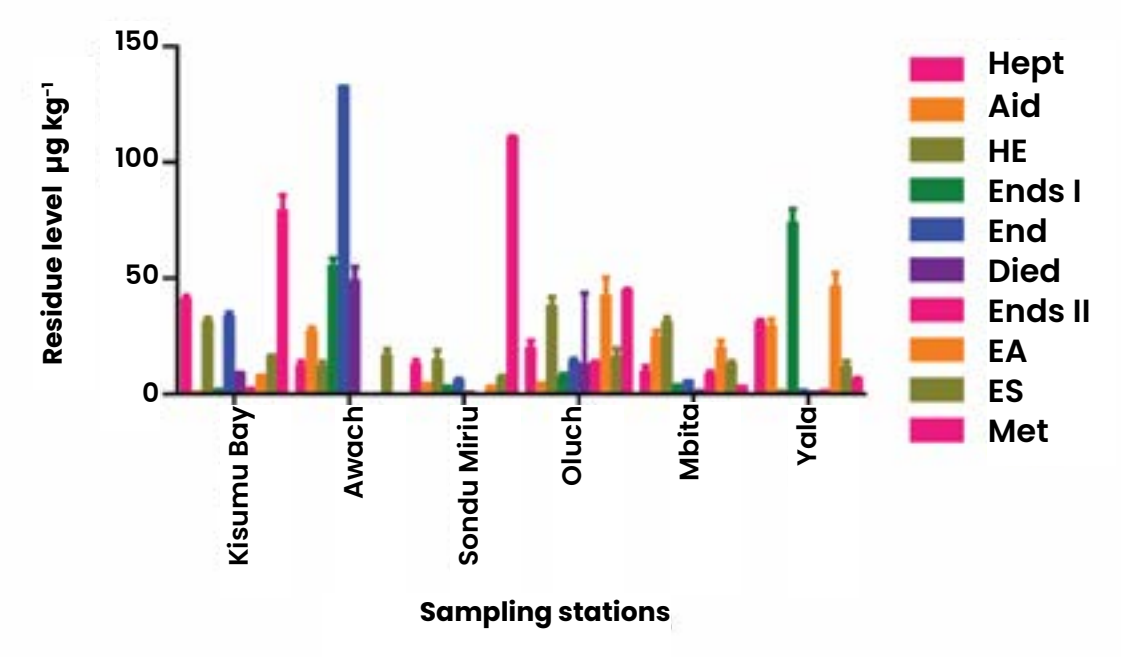

Figure 6. Generated pesticide levels as observed in sampled stations during the sampling period.

Endrin was undetectable in water samples from other sampled stations, except in the Kisumu Bay site (0.02 ± 0.0001 µg L^{-1}) and Sondu Miriu (0.13 ± 0.0001 µg L^{-1}) analysed water (Fig. 3). In the bottom sediment samples, endrin concentrations recorded were higher, at 86.7 ± 4.061 µg kg^{-1} in Kisumu, 19.2 ± 0.007 µg kg^{-1} in Mbita, and 13.13 ± 1.002 µg kg^{-1} residue levels in Sondu Miriu sampled stations (Fig. 4). Overall, endrin had a concentration of 0.01 ± 0.001 µg L^{-1} and 12.58 ± 0.724 µg kg^{-1} for water and sediment samples, respectively (Table 2). These concentrations were well above the WHO recommended limit of 0.6 ± 0.003 µg L^{-1} for drinking water as mean values observed in bottom sediments in this study exceeded the global thresholds. There is need to ensure continuous pesticides monitoring of its spatial and temporal loading variations since endrin can persist in the soil for more than a decade, and exposure to it causes severe harmful health effects to the central nervous system, vomiting, and convulsions and eventually leading to death in humans and livestock (Pathak *et al.,* 2022).

According to Abong'o *et al.* (2014), the main sources of organochlorine pesticide residues in the Lake Victoria region are agricultural ac-

tivities and use for public health vector control, such as mosquitoes. The high levels of pesticide residues detected in the sediments during this period occurred during the wet season and this was attributed to the runoff from the farms where the pesticides were previously applied. No organophosphates were detected in any of the water and sediment samples. *p,p'*- DDD which was identified at all sampling sites over a five-year span. Its results showed a markedly higher concentration followed by cyclodienes and the least was HCHs, in the order (DDTs > cyclodienes > HCHs), respectively.

Detection of pesticides methoxychlor, endosulphan, heptachlor, endrin and DDT which stand banned in Kenya pose serious risks to public health. According to Abongó *et al.* (2014), in a study on the impacts of pesticides on human health and the environment in the River Nyando catchment, pesticides were responsible for the development of symptoms of ill health where several farmers fell ill after exposure to these pesticides, although the authors could not point to any specific pesticide. For example, pesticides such as heptachlor have been reported to be highly toxic to humans causing hyperexcitation of the central nervous system and harm to the liver (US EPA, 2007).

Conclusion and recommendations

Even though a ban on the use of these OCPs took effect in Kenya almost two decades ago, the results of this study indicate that they are still within the Lake Victoria Basin. Fluxes were noted between different sampling sites with some residual concentrations, especially in sediments exceeding the WHO and NEMA recommended limits. Notably, concentrations in water samples than in sediments are considered crucial in this case due to their direct availability for use by biota and humans. However, public health may be under threat owing to the continued use of contaminated water since compounds such as heptachlor are persistent organic pollutants capable of biomagnifying in the food chain (Pérez-Ruzafa, 2000).

The rapid population growth and urbanization within Lake Victoria Basin in the last decade, coupled with intensive agricultural practices for food could be attributed to these pesticide residues encountered during this study. Therefore, due to environmental and public health concerns, there is a need for continuous mapping of point and non-point sources of pollution and monitoring of residual levels of these organochlorines to help in providing mitigation measures.

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