African Journal of Aquatic Science

ISSN: 1608-5914 (Print) 1727-9364 (Online) Journal homepage: http://www.tandfonline.com/loi/taas20

Occurrence and distribution of organochlorine pesticide residue levels in water, sediment and aquatic weeds in the Nyando River catchment, Lake Victoria, Kenya

DA Abong'o, SO Wandiga & IO Jumba

To cite this article: DA Abong'o, SO Wandiga & IO Jumba (2018) Occurrence and distribution of organochlorine pesticide residue levels in water, sediment and aquatic weeds in the Nyando River catchment, Lake Victoria, Kenya, African Journal of Aquatic Science, 43:3, 255-270, DOI: 10.2989/16085914.2018.1490244

To link to this article: https://doi.org/10.2989/16085914.2018.1490244

African Journal of Aquatic Science 2018, 43(3): 255–270

AFRICAN JOURNAL OF AQUATIC SCIENCE
ISSN 1608-5914 EISSN 1727-9364
https://doi.org/10.2989/16085914.2018.1490244

Occurrence and distribution of organochlorine pesticide residue levels in water, sediment and aquatic weeds in the Nyando River catchment, Lake Victoria, Kenya

DA Abong'o*, SO Wandiga and IO Jumba

College of Biological and Physical Sciences, School of Physical Science, Department of Chemistry, University of Nairobi, Nairobi, Kenya
** Corresponding author, email: dabongo@uonbi.ac.ke*

Samples of water, sediments and aquatic weeds were collected from 26 sites in the Nyando River catchment of the Lake Victoria basin in 2005–2006. The objective was to investigate levels of organochlorine pesticides that have either been banned or are restricted for use in Kenya. The pesticides investigated were lindane, aldrin, endosulfan, endrin, dieldrin, DDT, heptachlor and methoxychlor. These pesticides had previously found wide applications in public health and agriculture in Kenya for control of disease vectors and crop pests respectively. Results showed that mean concentrations were highest for methoxychlor (8.817 ± 0.020 µg l^{-1}) in water, sediments (92.893 ± 3.039 µg kg^{-1}), and weeds (39.641 ± 3.045 µg kg^{-1}), the weeds also tended to accumulate aldrin (15.519 ± 3.756 µg kg^{-1}). The results show that the pesticides are still in use and are detected in the catchment. Stringent management and public awareness measures are required to enforce the ban on the organochlorine pesticides in order to safeguard the environment and ecosystems of Lake Victoria.

Keywords: Agrochemicals, environmental pollution, farming, Winam Gulf

Introduction

Lake Victoria is the second largest fresh water lake in surface area in the world, second only to Lake Superior in North America; and has the world's largest freshwater fishery (LVEMP 2003). The Nile perch was introduced to the lake in 1954 to support an economically and socially important fishery export for the riparian countries, and has thrived remarkably well (LVEMP 2003). The lake has a wide drainage area of slightly more than 193 000 km^2 spreading to five countries, including Rwanda and Burundi, and supports the livelihood of more than 30 million people. Being the source of the White Nile River, it is therefore an important asset for all the countries within the Nile River Basin, including Egypt (LVEMP 2003). The lake's flushing time (volume/average outflow) is 138 years, and its residence time is 21 years. Because of this long retention time, pollutants entering the lake remain for a long time (LVEMP 2003).

The Committee for Inland Fisheries of Africa (CIFA) meeting held in Mwanza, Tanzania in 1989 noted the pollution problems were attributed to drainage water and run off into Lake Victoria by Kenyan rivers, as it has six major rivers draining pollutants into the lake. Winam Gulf was noted to be the most polluted catchment area on the Kenyan side (Calamari et al. 1995). Winam Gulf catchment has a total area of 11 994 km^2 and comprises the North and Southern Lakeshores, Nyando and Sondu-Miriu River catchments (LVEMP 2003).

All land uses in the Lake Victoria catchment in one way or another, affect the quality of the lake's water and that of its tributaries. For example, bad agricultural practices, such as cultivating on slopes adjacent to rivers and on river banks have caused massive soil erosion (Abong'o et al. 2015a). As a result of this, the rivers in Lake Victoria catchments are carriers of both sediments and nutrient loads that choke the lake (Shepherd et al. 2000, LVEMP 2003), with the Nyando and Kagera Rivers being more prominent. Sediments are the main carriers of pesticide residues, and organic and inorganic pollutants into the lake (LVEMP 2003). This has created a significant pollution problem that threatens the exploitation of the lake's water resources for national development. The Kenyan rivers flowing into the lake contribute a mean total volume of 7.3 billion m^3 water y^{-1} (Calamari et al. 1995). The main ones are Sio, Nzoia, Yala, Sondu-Miriu, Nyando and Gucha/Migori Rivers; and between them are many minor streams (Calamari et al. 1995).

Studies aimed at providing baseline information on the levels of organochlorine pesticide residues in the aquatic system of the lake showed previous use of DDT and significant use of lindane and endosulfan within the Lake Victoria basin in Uganda (Mbabazi 1998; Kasozi 2006). Pollution of lake waters by pesticides has also been reported on the Tanzanian side of the lake in various studies (IUCN 1992; Cru Ruud 1995; Kashimba et al. 2004). The Ugandan part of the Lake Victoria has also been found to have pesticides used for killing bird pests (Sentongo 1998) and in fishing (Orgaram 1992). The organochlorine pesticides that have either been banned or are restricted for use in Kenya include DDT, lindane, aldrin, dieldrin, heptachlor, endrin, endosulfan and methoxychlor. Prior to their ban or restriction in use, they had found wide applications in public health for control of disease vectors and in agriculture for control

African Journal of Aquatic Science is co-published by NISC (Pty) Ltd and Informa UK Limited (trading as Taylor & Francis Group)

Published online 20 Sep 2018

of crop pests. Their breakdown products have also been reported in the environment and are more persistent than the parent compounds (Lalah et al. 2001).

Aldrin has been widely used to protect crops, such as corn and potatoes, and has been effective in protecting wooden structures from drainage by termites. Its use has, however, been banned in Kenya (Abong'o et al. 2015a). Aldrin is rapidly metabolised to dieldrin, by both plants and animals, but because of its persistent nature and hydrophobicity, it is known to bioconcentrate, mainly as its conversion products (ATSDR 2005). DDT is used in controlling the malaria vector in the public health sector, its formulation contains the p'-p' and o'-p' isomers and therefore both have to be determined during DDT quantification in any medium. In addition, the two main metabolites, DDE and DDD (sometimes called TDE) are also commonly determined, because both of these compounds can be produced from the p'-p' and o'-p' isomers of DDT (Cox 2002). Heptachlor is rapidly hydrolysed in water to give an intermediate that is converted to the epoxide. In animals, heptachlor metabolises to the epoxide, which can be found in most body organs, but it particularly accumulates in body fats. Endosulfan is soluble in water and the main metabolite is endosulfan sulphate, which is degraded more slowly and is therefore an important metabolite to analyse (Cox 2002).

Environmental fate of organochlorine pesticides has become an issue not only in Kenya, but also in many developing and developed countries. Despite the official ban and restriction on these pesticides in Kenya in 1986, they are still being detected in the environment (Lalah et al. 2001; Abong'o et al. 2015a). Because of their environmental and health implication, there is a need to monitor their residue levels and that of their metabolites in the environment.

In May 1999, press reports indicated that fish were being harvested from the Lake Victoria by use of endosulfan insecticide. This resulted in the imposition of a fish import ban by the European Union (EU) on all fish from Lake Victoria (European Commission 1999). The EU demanded that Kenya, Uganda and Tanzania submit a list of all chemicals sold in the region, their toxicity to humans and their persistence in fish and water before any negotiations begun. Total loss of income because of the ban was estimated to be more than US$ 300 million in 1999 (European Commission 1999). Within the Kenyan lake basin, pesticides and fertilisers have been increasingly used to boost agricultural products (Getenga et al. 2004; Abong'o et al. 2014). Increased run-off laden with pesticides and fertilisers from these farms is inevitably finding its way into Lake Victoria through the rivers draining the basin (Abong'o et al. 2015a). Inevitably the residues are finding their way into the lake waters (Calamari et al. 1995; Getenga et al. 2004; Abong'o et al. 2015a). There is no evidence that a comprehensive analysis of pesticide use, distribution and fate has been done on water, fish and environment in Lake Victoria or any of its drainage systems to date. There is very little information on Lake Victoria and its waterways (Getenga et al. 2004; Abong'o et al. 2014; Abong'o et al. 2015a). Lack of this information has resulted in the absence of surveillance programs for pesticide residue levels in the agricultural and fisheries products from the Lake Victoria basin.

Because of the CIFA concerns in 1989, the imposition of fish import ban by the EU in 1999 and evidence from scarce data available from studies conducted within the lake basin (Getenga.et.al. 2004; Abong'o et al. 2015a), it is important to focus on the pollution status of the Winam Gulf catchment with special emphasis on the Nyando River drainage basin. Monitoring of Nyando River, which is the major Kenyan river source of sedimentation into the lake, is important for the restoration and management of the lake as part of a long-term strategy to conserve ecology in the lake basin. If a well-targeted comprehensive analysis is done for one drainage system, for example, the result forms the basis for the study of the other waterways and that of the entire lake itself.

Materials and methods

Study area

The Nyando River (Figure 1) has a total length of 170 km and a catchment area of 3 450 km^2. The catchment area lies between 0°25′ S to 0°10′ N and 34°50′ W to 35°50′ E. The river has two main tributaries, small Nyando (Kericho-upper Nyando) and Ainamotua River (Nandi-lower Nyando). The Nyando basin drains major agricultural and industrial zones of western Kenya and has the highest average sediment transport capacity index (0.30) and average slope (5%) of all rivers draining into Lake Victoria (LVEMP 2003). There are severe widespread land degradation problems throughout the Nyando River basin, which affect an estimated 1 444–1 932 km^2 of its area (Odada et al. 2009). The principal causes of erosion in the basin include deforestation of the headwaters and slash-and-burn agricultural activities that cover extensive areas of fragile lands on both hill slopes and plains. The deforestation is coupled with loss of watershed filtering functions through encroachment on the wetlands and loss of riverine vegetation (Abong'o et al. 2015b).

Sampling plan and sites

Two areas of the Nyando River basin were investigated: the Kericho-Upper Nyando and Nandi-Lower Nyando Subcatchments. Twenty-six sampling sites representative of the study area were identified by the Lake Victoria Environment Management Project (LVEMP) Pollution Loading Component in Kenya (Figure 1). Sites 1 to 14 were identified in the Kericho-Upper Nyando Subcatchments, whereas Sites 15 to 33 was for the Nandi-Lower Nyando basin (Table 1). Water, sediment and aquatic weed samples were collected from the sites. The sampling was done twice, in February and May 2005, and repeated in 2006 to capture the effects of different seasons and farming activities on residue levels of the pesticides. Samples collected in February were mainly to capture the effects of dry season (January–February) when farmers plough the farms and apply the pesticides to soil to kill soil dwelling pests prior to planting in March and April. Samples collected in May were to capture the effects of the long rains (wet season) on pesticides applied with pre and post-emergence. Typically, February and May are the driest and wettest months, respectively (Abong'o et al. 2015b).

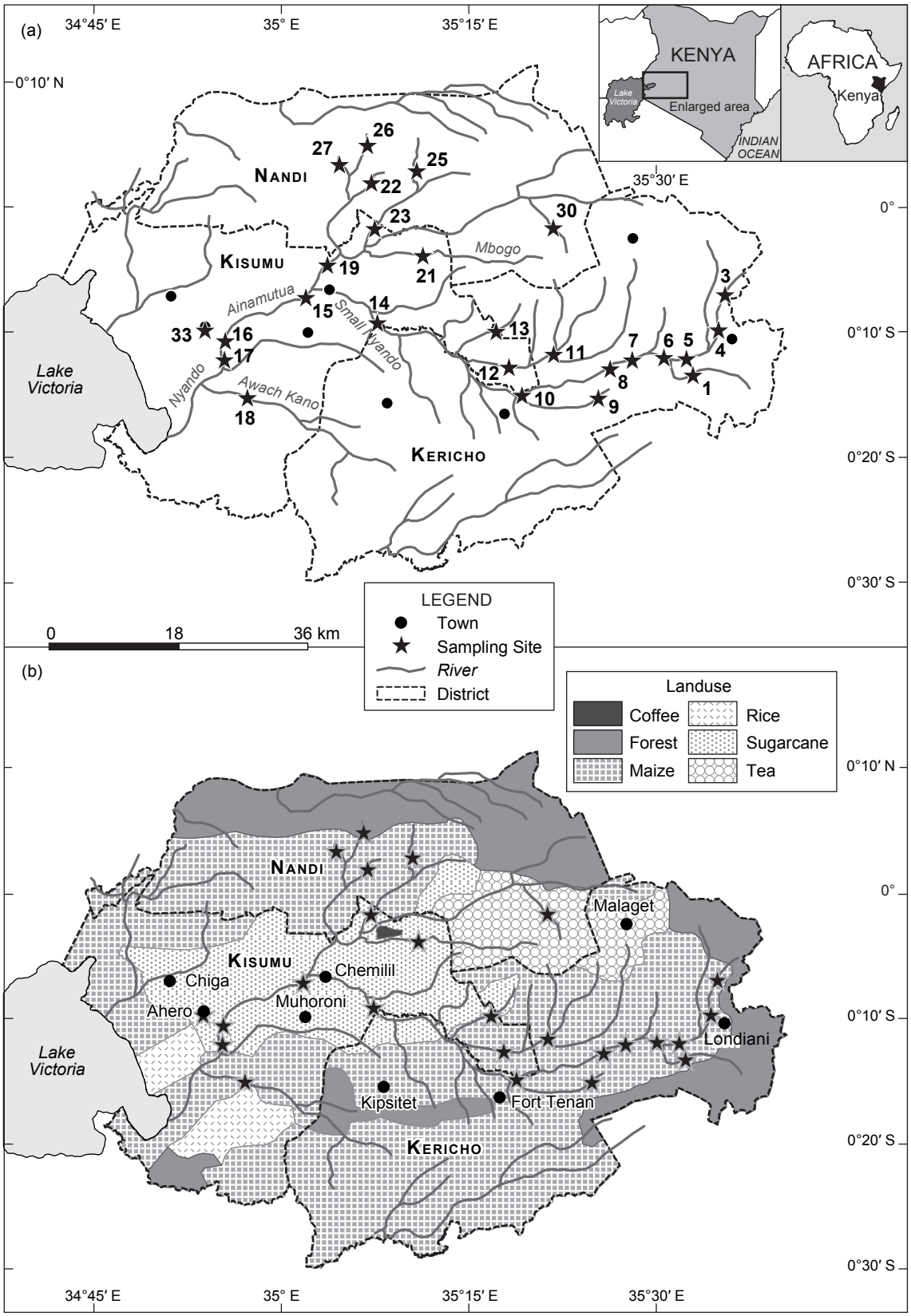

Figure 1: Map of the Nyando River drainage basin showing land use and sampling site locations

Table 1: Description of sampling sites in the Nyando River catchment

Site no.	Name	Coordinates		Altitude	Human activities around the site
		Latitude	Longitude	(m)	
1	Kedowa at bridge	00°14'02.4" S	35°32'42" E	2 290	Subsistence agriculture and depleted forest cover
3	Masaita at dam	00°08'06" S	35°36'07.2" E	2 310	Subsistence agriculture and depleted forest cover
4	Masaita at Londiani Township	00°09'46.8" S	35°32'09.6" E	2 290	Human settlement, subsistence agriculture on river banks, cattle and sheep watering, raw sanitation effluent discharge into the river
5	Masaita at Lambel Farm	00°11'24" S	35°32'09.6" E	2 050	Cattle grazing, recreation
6	Kipchorian at Tuiyobei	00°11'49.2" S	35°30'43.2" E	2 000	Subsistence agriculture
7	Kimoson	00°12'25.2" S	35°27'50.4" E	1 920	Subsistence agriculture on the river banks, cattle and sheep watering
8	Nyando at Kipkelion	00°12'25.2" S	35°27'43.2" E	1 920	Subsistence agriculture on the river banks, cattle watering, recreation
9	Tugunon at bridge	00°15'00" S	35°24'54" E	2 000	Subsistence agriculture
10	Namting at Fort Ternna	00°12'14.4" S	35°20'49.2" E	1 560	Sugarcane farming, subsistence agriculture
11	Murgut at Koru	00°12'50.4" S	35°19'08.4" E	1 500	Sugarcane farming, subsistence agriculture and recreation
12	Pararget at bridge	00°12'43.2" S	35°18'03.6" E	1 500	Sugarcane farming, subsistence agriculture on river banks and recreation
13	Homa Lime	00°11'2.4" S	35°17'56.4" E	1 320	Sugarcane farming, subsistence agriculture on river banks, discharge of factory effluent from calcium carbonate factory
14	Nyando at Muhoroni bridge	00°09'57.6" S	35°11'02.4" E	1 280	Sugarcane farming, subsistence agriculture on river banks, recreation
Nandi-Lower Nyando Subcatchment					
15	Nyando at Ogilo	00°09'57.6" S	35°9'43.2" E	1 190	Sugarcane farming, subsistence agriculture, recreation
16	Nyando at Ahero bridge	00°10'19.2" S	35°55'15.6" E	1 170	Human settlement, livestock rearing, subsistence agriculture, solid wastes on river banks coupled with recreation
17	Nyando at dykes	00°12'3.6" S	34°55'44.4" E	1 150	Constructed dykes, discharge raw domestic sanitation from Ahero town, cattle watering and recreation
18	Awach Kano	00°14'2.4" S	34°57'25.2" E	1 150	Irrigated rice farming. cattle watering coupled with subsistence agriculture and recreation
19	Ainamutua-Kibigori	00°04'33.6" S	35°03'21.6" E	1 210	Sugarcane farming, cattle watering and Subsistence agriculture and river sand harvesting
21	Mbogo	00°03'39.6" S	35°08'52.8" E	1 270	Sugarcane farming, subsistence agriculture on river banks, recreation
22	Anopsiwa	00°01'48" N	35°07'04.8" E	1 320	Large scale sugarcane farming, river sand harvesting and recreation
23	Anopngetuny	00°01'40.8" S	35°07'04.8" E	1 330	Large scale coffee and sugarcane farming,
25	Chemwanabei	00°03'54" N	35°07'04.8" E	1 820	Large scale tea farming
26	Kapngorium at Bridge	00°03'14.4" N	35°06'00" E	1 850	Human settlement, large scale tea farming, subsistence agriculture, raw effluent from tea factory
27	Kundos at Bridge	00°03'03.6" N	35°03'43.2" E	1 850	Large scale tea farming, subsistence agriculture
30	Chebirirkut at dam	00°02'13.2" S	35°20'52.8" E	1 820	Forest, no human settlement or activities
33	Ahero irrigation channel	10°19'12.0" S	34°54'28.8" E	1 150	Irrigated rice farming, cattle watering and recreation

Materials

Chemicals used were of analytical grade or equivalent and were obtained from international suppliers, including Fisher Scientific (USA), Aldrich Chemical Company and BDH (United Kingdom). Organochlorine pesticide reference standards were obtained from Dr Ehrenstorfer GmbH Company (Germany). All the general purpose solvents (acetone and hexane) used were triple distilled before use. Other solvents, such as diethyl either and HPLC grade hexane 99%), were used as supplied. However, purity of the HPLC grade hexane was confirmed by concentrating the solvent and running its Gas Chromatogram to determine whether there were any peaks other than those of the solvent. Sodium chloride and activated charcoal were baked at 120 °C in a Mermmert oven for at least two hours and cooled in desiccators before use. Florisil and anhydrous sodium sulphate were activated at 350 °C and 200 °C, respectively, before use for the clean-up process (UNESCO 1993). Detergents for washing glassware were bought from suppliers in Nairobi. Cleared glassware and crucibles were soaked in chromic acid for at least two hours, washed with tap water, rinsed with distilled water, and finally with triply distilled methanol. The apparatus were then dried in a Gallenkamp oven for 4–5 hours at 105 °C before use.

Water sampling, extraction and analysis

Triplicate water samples were collected from each sampling site by grab sampling method into labelled 2.5 litre amber glass bottles. For recovery studies, one of the samples was spiked with 10 ml of 100 mg l^{-1} of the pesticide standard mixture. Sodium chloride (100 g) was added to all samples for preservation and temporarily stored in polyurethane cool boxes containing dry ice for transportation to the laboratory. Extraction of water samples was done using the US EPA Method 3510 C (USEPA 1996). In all, 2 litres of each sample were transferred to 3 litres beaker. 50 ml of 0.2 M dipotassium hydrogen phosphate buffer was added and the mixture stirred and the pH recorded, then adjusted by adding drops of 0.1 N hydrochloric acid (HCl) or 0.1 M sodium hydroxide solutions (NaOH) with stirring to pH 7.0. The neutral solution was then transferred to a 2–litre separating funnel and shaken with 100 g of activated sodium chloride (NaCl). The function of NaCl was to salt out the pesticides from the aqueous phase to organic layer. The mixture was then extracted by shaking with 60 ml triple distilled dichloromethane and allowed to settle for 30 minutes to enhance separation of the layers. The extraction was performed in triplicate.

The organic layer extract was separated and dried using activated anhydrous sodium sulphate (Na_2SO_4), with 2 ml of isooctane added as a keeper. The function of isooctane was to prevent samples from running dry, depending on final volume. The extract was concentrated to about 3 ml using LABCONCO rotator evaporator. The concentrate was cleaned by passing through alumina chromatographic column 25 cm long × 1.5 cm inside diameter packed in succession with 1 g of activated anhydrous Na_2SO_4, 15 g of deactivated alumina, and 1 g of activated anhydrous Na_2SO_4, contents were then preconditioned by draining 15 ml of HPLC grade-hexane though the column. The extract was eluted with 165 ml of the HPLC grade-hexane into a precleaned round bottom flask. Iso-octane (2 ml) was added to the eluent as a keeper and contents concentrated to about 1 ml using the rotary evaporator. The concentrate was then transferred into a clean preweighed auto sample vial and concentrated further to 0.5 ml under a gentle stream of white spot nitrogen for GC analysis. Reference standards of each organochlorine pesticide were used for calibration in the various steps of the analysis. For each sample, 1 µl was injected into the Varian Chrompack CP-3800 Gas Chromatograph (GC) and eluted, using helium as the carrier gas. Data processing was done using Star Version 5.4.

Sediments sampling, extraction and analysis

Six cores of sediment were scooped within a length of 50 m below the water surface from left bank, midstream and right river bank using Ekman sampler (Cox 2002). The samples were thoroughly mixed and four replicate portions of approximately 100 g each were subsampled. Two of the replicate samples were each wrapped in aluminium foil, labelled and placed in black plastic bag before transferring to a labelled self-sealing polythene bag. Each sealed bag was enclosed in a plastic container with lid and transported in polyurethane cool-boxes containing dry ice prior to the laboratory for analysis. The other two replicates were treated for field recoveries. They were placed in aluminium foil and spiked with 4 ml of 100 mg kg^{-1} of desired pesticide standard mixture and packed as for Batch A. In the laboratory, samples were stored at ≤19 °C awaiting extraction and analysis, extraction was done within 10 days. Samples were left to thaw overnight and air dried. Pebbles, stones, and plant materials were removed from the air dried samples. The samples were crushed and homogenised in mortar and pestle and sieved through 250 µm mesh sieve. A triplicate 10 g portion of each sample was thoroughly mixed with the equivalent amount of activated anhydrous Na_2SO_4, and transferred to extraction Soxhlet thimble.

Isodrin solution was added as an internal standard (100 µl of 0.01 mg l^{-1}) contents mixed and then extracted using the EPA method 3540. The extracts were then concentrated to 2 ml, mixed with 2 ml isooctane, and further concentrated with a LABCONCO rotary evaporator. The concentrate was transferred into a 10 ml glass sample vials, which had been precleaned with 2 ml HPLC-grade hexane and taken for the clean-up process. To remove any sulphur from the sediment sample extracts, approximately 1 g of freshly activated copper powder was added. The mixture was filtered through a glass funnel containing glass wool and 2 g of activated anhydrous Na_2SO_4 added. 5 ml of HPLC grade hexane was used to recondition the filter funnel prior to use for filtration. The sample extract was eluted thrice with 20 ml of HPLC grade-hexane into round bottom flask, concentrated to about 3 ml, cleaned by eluting through the alumina chromatographic column, as in the case when using water, concentrated to about 1 ml using the rotary evaporator, and finally transferred to sample auto vials. The eluent was concentrated to 0.5 ml under a gentle stream of nitrogen and taken for analysis by GC.

Aquatic weeds sampling, extraction and analysis

Aquatic weeds samples at each site were harvested using a stainless steel knife, wrapped in pre-extracted aluminium foil and transferred to labelled self sealing polythene bags prior to transportation to the laboratory. Portions of the samples were taken to the University of Nairobi's Herbarium for taxonomic identification, whereas the remaining were thoroughly washed with methanol to remove soil particles and then dried in an oven at 50 °C. The dried samples were chopped and minced, 10 g of minced samples were weighed in triplicate and each Soxhlet extracted according to the USEPA method 3510, using a mixture of hexane and acetone in 3:1 (v/v ratio), respectively for sixteen hours. Each extract was rotary evaporated to about 10 ml, cleaned by eluting through alumina chromatographic column, as in the case when using water. Then, 2 ml of iso-octane was added to each extract, and the mixture shaken and concentrated to about 1 ml. Contents were transferred to a clean preweighed auto sample vial and concentrated to 0.5 ml under a gentle stream of white spot nitrogen before GC analysis.

Data analysis

The data obtained was analysed using statistical programme for social scientists (SPSS 22) to establish relationship between pesticide residue levels in the samples from different sampling sites and the sampling seasons. Bivariate correlation coefficients were established using the Pearson product-moment correlation coefficient, R, a

dimensionless index, whose value is in the range $-1.0 \leq R \leq 1.0$.

Results

Percentage recoveries of organochlorine pesticides levels from the spiked samples and the distribution of aquatic weeds

The pesticide residue levels detected in the water, sediments and weed samples were not corrected for matrix effects, because all recovery values (76–90%) (Table 2) fell within the acceptable range of 70 to 120% (Hill 2000). A total of 16 pesticides, including their metabolites, was monitored and detected in the samples at mean frequencies ranging from 19–56% for water, 28–89% for sediment and 28–53% for weeds. Three weed species were dominant at the twenty six sampling sites (Table 3). The weeds were classified as *Cyperus distans* with 52% frequencies in Nyando River, followed by *Cyperus alternifolius* (26%), *Cyperus rotundus* (11%), *Eichhornia crassipes* (water hyacinth) (7%) and *Asystasia gangetica* (4%) (Table 4).

Seasonal variations in pesticide residue levels in Kericho-Upper Nyando Subcatchment area

Mean concentrations for organochlorine pesticide residue levels in water, sediments and weeds in the dry (February) and wet (May) seasons in Kericho-Upper Nyando area are presented in Tables 5 and 6. The average pesticide residue levels in the driest month for water, sediments and weeds in the upper subcatchment are shown in Table 5. Out of the sixteen pesticide monitored during the dry season, Site 8 showed the highest frequency (56%) of residues detected in water samples, 88% in sediments at Site 14 and 75% for weeds at Site 9 (Table 5). In the wettest month, residue levels detected for water, sediment and aquatic weeds are shown in Table 6. Site 14 showed the highest frequency (69%) of pesticides levels detection in water samples, 93% sediments at Site 14 and 63% for weeds at Sites 8 (Table 6).

In Kericho-Upper Nyando Subcatchment, the pesticides concentrations detected in water in February showed strong positive bivariate Pearson correlation coefficients

Table 3: Distribution of aquatic weeds at sample sites in the Nyando River catchment in 2005–2006.

Site	Aquatic weed distribution
1	*Cyperus alternifolius*
3	*Cyperus distans*
4	*Cyperus distans*
5	*Cyperus distans*
6	*Cyperus distans*
7	*Cyperus distans*
8	*Cyperus distans*
9	*Cyperus alternifolius*
10	*Cyperus alternifolius*
11	*Cyperus distans*
12	*Cyperus distans*
13	*Cyperus distans*
14	*Cyperus distans*
15	*Cyperus alternifolius*
16	*Cyperus alternifolius*
17	*Cyperus distans*
18	*Eichhornia crassipes* (water hyacinth)
19	*Cyperus distans*
21	*Cyperus distans, Cyperus alternifolius*
22	*Cyperus alternifolius*,
23	*Cyperus distans*
25	*Cyperus alternifolius*
26	*Cyperus rotundus*
27	*Cyperus distans*
30	*Asystasia gangetica*
33	*Eichhornia crassipes*

Table 4: Percentage distribution of aquatic weeds at sample sites in the Nyando River catchment in 2005–2006

Taxon	Percentage distribution of aquatic weeds
Poles	
Cyperus distans	52
Cyperus alternifolius	26
Cyperus rotundus	11
Commelinales	
Eichhornia crassipes	7
Lamiales	
Asystasia gangetica	4

Table 2: Percentage recoveries of organochlorine pesticide residues in water, sediment and weeds. At sampling sites in the Nyando River basin in 2005–2006

Pesticides	Water (µg l^{-1})	Sediment (µg kg^{-1}, DW)	Weeds (µg kg^{-1}, DW)
Lindane	88.152 ± 2.642	78.401 ± 1.009	76.409 ± 1.012
p,p'-DDT	96.124 ± 3.052	80.483 ± 2.227	79.211 ± 1.021
o,p'-DDE	96.101 ± 2.015	81.515 ± 1.605	79.052 ± 2.061
p,p'-DDD	92.025 ± 2.251	88.043 ± 2.225	85.245 ± 1.043
α-endosulfan	90.545 ± 3.215	84.213 ± 2.014	80.210 ± 1.035
β-Endosulfan	89.113 ± 4.312	86.023 ± 2.702	83.601 ± 2.026
Endosulfan Sulphate	90.089 ± 3.325	83.381 ± 2.037	80.712 ± 1.045
Aldrin	86.411 ± 1.115	85.363 ± 1.298	79.245 ± 0.871
Dieldrin	94.243 ± 4.254	79.266 ± 1.427	77.324 ± 1.210
Endrin	88.226 ± 2.013	78.659 ± 2.127	77.210 ± 2.011
Heptachlor	90.024 ± 1.561	80.752 ± 1.357	78.123 ± 1.013
Heptachlor-epoxide	89.162 ± 1.093	81.488 ± 3.165	79.056 ± 1.056
Methoxychlor	94.188 ± 2.212	89.192 ± 1.127	87.106 ± 1.034

n = 6, mean ± SD, DW = dry weight

Table 5: Pesticide residue levels (µg l^{-1}) in water, (µg kg^{-1}, DW) sediment and weeds (µg kg^{-1}, DW) from Kericho-Upper Nyando in February

Site pesticide	1	2	3	4	5	6	7	8	9	10	11	12	13
Water													
aldrin	16.339 ± 1.580	21.172 ± 0.788	9.455 ± 1.209	8.169 ± 1.494	9.401 ± 1.568	0.971 ± 0.017	2.3655 ± 0.425	0.712 ± 0.332	1.956 ± 0.026	2.979 ± 1.246	3.922 ± 0.280	BDL	0.180 ± 0.072
dieldrin	6.087 ± 0.125	2.673 ± 0.439	BDL	BDL	6.808 ± 0.368	0.059 ± 0.007	1.554 ± 0.569	0.035 ± 0.071	6.769 ± 0.967	1.511 ± 0.666	0.043 ± 0.005	0.154 ± 0.052	1.236 ± 0.020
endosulfan S	0.300 ± 0.028	0.282 ± 0.190	0.039 ± 0.003	0.265 ± 0.078	1.867 ± 0.110	1.204 ± 0.221	0.049 ± 0.013	3.980 ± 0.649	0.040 ± 0.008	4.462 ± 0.737	1.666 ± 0.033	0.266 ± 0.073	2.131 ± 0.177
α-endosulfan	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
β-endosulfan	BDL	1.061 ± 0.057	2.225 ± 0.290	0.065 ± 0.007	BDL	0.187 ± 0.014	2.499 ± 0.215	1.492 ± 0.416	0.015 ± 0.007	0.104 ± 0.001	1.156 ± 0.066	0.014 ± 0.002	BDL
endrin	1.154 ± 0.154	0.030 ± 0.003	1.611 ± 0.994	0.182 ± 0.011	0.288 ± 0.014	0.351 ± 0.008	0.030 ± 0.014	BDL	0.860 ± 0.105	1.900 ± 0.124	1.352 ± 0.120	BDL	1.662 ± 0.139
heptachlor	BDL	BDL	0.037 ± 0.005	BDL	0.064 ± 0.011	BDL	0.083 ± 0.011	BDL	BDL	BDL	BDL	BDL	0.610 ± 0.091
Heptachlor-epoxide	BDL	BDL	0.059 ± 0.007	0.164 ± 0.014	0.179 ± 0.006	1.005 ± 0.131	BDL	1.387 ± 0.408	0.539 ± 0.167	0.450 ± 0.072	0.080 ± 0.014	0.222 ± 0.014	0.429 ± 0.086
lindane	1.877 ± 0.051	BDL	9.401 ± 0.900	4.351 ± 0.459	9.741 ± 0.424	5.765 ± 1.025	2.839 ± 0.992	3.343 ± 0.833	0.873 ± 0.042	5.440 ± 0.647	8.154 ± 1.238	0.945 ± 0.071	10.971 ± 0.104
methoxychlor	14.330 ± 1.658	17.328 ± 2.915	61.527 ± 3.656	67.439 ± 4.700	65.454 ± 1.881	50.825 ± 2.745	19.796 ± 1.249	29.752 ± 1.782	44.694 ± 0.479	52.411 ± 3.865	58.101 ± 5.546	94.619 ± 3.882	92.893 ± 3.039
o,p'-DDT	BDL	0.024 ± 0.012	BDL	BDL	BDL	BDL	BDL	BDL	0.184 ± 0.008	0.256 ± 0.015	BDL	BDL	1.245 ± 0.470
p,p'-DDT	0.485 ± 0.118	1.454 ± 0.311	2.894 ± 0.324	0.993 ± 0.009	0.983 ± 0.022	1.178 ± 0.021	0.344 ± 0.030	1.430 ± 0.315	0.319 ± 0.010	0.900 ± 0.113	1.178 ± 0.017	0.433 ± 0.049	2.761 ± 0.146
o,p'-DDD	0.162 ± 0.010	0.289 ± 0.003	0.902 ± 0.119	BDL	0.360 ± 0.002	BDL	BDL	0.902 ± 0.050	0.170 ± 0.003	0.0033 ± 0.007	0.363 ± 0.050	BDL	0.382 ± 0.076
p,p'-DDD	0.199 ± 0.066	0.122 ± 0.017	BDL	BDL	0.361 ± 0.003	0.288 ± 0.013	0.155 ± 0.070	1.302 ± 0.066	1.143 ± 0.048	BDL	0.869 ± 0.163	0.664 ± 0.067	1.531 ± 0.487
o,p'-DDE	0.683 ± 0.036	BDL	0.567 ± 0.152	0.314 ± 0.001	BDL	BDL	0.590 ± 0.004	0.764 ± 0.188	0.214 ± 0.007	BDL	1.885 ± 0.140	BDL	0.965 ± 0.016
p,p'-DDE	1.193 ± 0.008	0.361 ± 0.052	5.203 ± 0.305	1.174 ± 0.008	0.729 ± 0.239	2.313 ± 0.4669	0.395 ± 0.093	0.237 ± 0.037	0.255 ± 0.052	0.915 ± 0.104	3.967 ± 0.256	0.259 ± 0.009	1.902 ± 0.112
Sediment													
aldrin	16.339 ± 1.580	21.172 ± 0.788	9.455 ± 1.209	8.169 ± 1.494	9.401 ± 1.568	0.971 ± 0.017	2.3655 ± 0.425	0.712 ± 0.332	1.956 ± 0.026	2.979 ± 1.246	3.922 ± 0.280	BDL	0.180 ± 0.072
dieldrin	6.087 ± 0.125	2.673 ± 0.439	BDL	BDL	6.808 ± 0.368	0.059 ± 0.007	1.554 ± 0.569	0.035 ± 0.071	6.769 ± 0.967	1.511 ± 0.666	0.043 ± 0.005	0.154 ± 0.052	1.236 ± 0.020
endosulfan S	0.300 ± 0.028	0.282 ± 0.190	0.039 ± 0.003	0.265 ± 0.078	1.867 ± 0.110	1.204 ± 0.221	0.049 ± 0.013	3.980 ± 0.649	0.040 ± 0.008	4.462 ± 0.737	1.666 ± 0.033	0.266 ± 0.073	2.131 ± 0.177
α-endosulfan	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
β-endosulfan	BDL	1.061 ± 0.057	2.225 ± 0.290	0.065 ± 0.007	BDL	0.187 ± 0.014	2.499 ± 0.215	1.492 ± 0.416	0.015 ± 0.007	0.104 ± 0.001	1.156 ± 0.066	0.014 ± 0.002	BDL
endrin	1.154 ± 0.154	0.030 ± 0.003	1.611 ± 0.994	0.182 ± 0.011	0.288 ± 0.014	0.351 ± 0.008	0.030 ± 0.014	BDL	0.860 ± 0.105	1.900 ± 0.124	1.352 ± 0.120	BDL	1.662 ± 0.139
heptachlor	BDL	BDL	0.037 ± 0.005	BDL	0.064 ± 0.011	BDL	0.083 ± 0.011	BDL	BDL	BDL	BDL	BDL	0.610 ± 0.091
Heptachlor-epoxide	BDL	BDL	0.059 ± 0.007	0.164 ± 0.014	0.179 ± 0.006	1.005 ± 0.131	BDL	1.387 ± 0.408	0.539 ± 0.167	0.450 ± 0.072	0.080 ± 0.014	0.222 ± 0.014	0.429 ± 0.086
lindane	1.877 ± 0.051	BDL	9.401 ± 0.900	4.351 ± 0.459	9.741 ± 0.424	5.765 ± 1.025	2.839 ± 0.992	3.343 ± 0.833	0.873 ± 0.042	5.440 ± 0.647	8.154 ± 1.238	0.945 ± 0.071	10.971 ± 0.104
methoxychlor	14.330 ± 1.658	17.328 ± 2.915	61.527 ± 3.656	67.439 ± 4.700	65.454 ± 1.881	50.825 ± 2.745	19.796 ± 1.249	29.752 ± 1.782	44.694 ± 0.479	52.411 ± 3.865	58.101 ± 5.546	94.619 ± 3.882	92.893 ± 3.039
o,p'-DDT	BDL	0.024 ± 0.012	BDL	BDL	BDL	BDL	BDL	BDL	0.184 ± 0.008	0.256 ± 0.015	BDL	BDL	1.245 ± 0.470
p,p'-DDT	0.485 ± 0.118	1.454 ± 0.311	2.894 ± 0.324	0.993 ± 0.009	0.983 ± 0.022	1.178 ± 0.021	0.344 ± 0.030	1.430 ± 0.315	0.319 ± 0.010	0.900 ± 0.113	1.178 ± 0.017	0.433 ± 0.049	2.761 ± 0.146
o,p'-DDD	0.162 ± 0.010	0.289 ± 0.003	0.902 ± 0.119	BDL	0.360 ± 0.002	BDL	BDL	0.902 ± 0.050	0.170 ± 0.003	0.0033 ± 0.007	0.363 ± 0.050	BDL	0.382 ± 0.076
p,p'-DDD	0.199 ± 0.066	0.122 ± 0.017	BDL	BDL	0.361 ± 0.003	0.288 ± 0.013	0.155 ± 0.070	1.302 ± 0.066	1.143 ± 0.048	BDL	0.869 ± 0.163	0.664 ± 0.067	1.531 ± 0.487
o,p'-DDE	0.683 ± 0.036	BDL	0.567 ± 0.152	0.314 ± 0.001	BDL	BDL	0.590 ± 0.004	0.764 ± 0.188	0.214 ± 0.007	BDL	1.885 ± 0.140	BDL	0.965 ± 0.016
p,p'-DDE	1.193 ± 0.008	0.361 ± 0.052	5.203 ± 0.305	1.174 ± 0.008	0.729 ± 0.239	2.313 ± 0.4669	0.395 ± 0.093	0.237 ± 0.037	0.255 ± 0.052	0.915 ± 0.104	3.967 ± 0.256	0.259 ± 0.009	1.902 ± 0.112
Weeds													
aldrin	15.519 ± 3.756	BDL	BDL	9..216 ± 1.504	BDL	BDL	BDL	1.874 ± 0.002	BDL	BDL	BDL	BDL	0.928 ± 0.068
dieldrin	BDL	5.129 ± 0.909	6.151 ± 0.665	BDL	8.001 ± 0.303	2.905 ± 6.530	7.431 ± 0.305	0.935 ± 0.008	8.275 ± 0.353	BDL	1.526 ± 1.152	BDL	3.516 ± 0.739
endosulfan S	9.433 ± 2.470	5.836 ± 2.605	6.758 ± 0.941	1.205 ± 0.031	6.559 ± 0.053	7.427 ± 1.909	3.948 ± 0.408	4.104 ± 0.021	BDL	BDL	BDL	BDL	BDL
α-endosulfan	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
β-endosulfan	3.818 ± 0.454	BDL	BDL	0.197 ± 0.016	BDL	BDL	BDL	2.012 ± 0.132	BDL	BDL	BDL	BDL	BDL
endrin	BDL	BDL	BDL	0.273 ± 0.091	BDL	BDL	8.200 ± 1.474	BDL	7.001 ± 0.203	BDL	BDL	BDL	BDL
heptachlor	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Heptachlor-epoxide	BDL	BDL	BDL	0.164 ± 0.014	BDL	BDL	BDL	1.387 ± 0.408	BDL	BDL	BDL	BDL	2.102 ± 0.380
lindane	5.613 ± 1.580	2.801 ± 0.755	2.944 ± 0.378	4..351 ± 0.459	2.658 ± 0.116	8.387 ± 1.04	8.160 ± 0.460	3.343 ± 0.833	7.117 ± 0.216	BDL	BDL	BDL	7.068 ± 0.451
methoxychlor	39.641 ± 8.045	36.499 ± 8.460	13.378 ± 1.361	23.430 ± 1.001	25.326 ± 0.460	34.798 ± 0.913	42.094 ± 4.015	29.752 ± 1.782	8.311 ± 1.260	BDL	8.572 ± 2.217	BDL	29.039 ± 2.801
o,p'-DDT	4.894 ± 1.854	BDL	BDL	BDL	BDL	BDL	1.757 ± 0.360	BDL	BDL	BDL	BDL	BDL	BDL

Table 5: (cont.)

Site pesticide	1	2	3	4	5	6	7	8	9	10	11	12	13
p,p'-DDT	BDL	4.849 ± 0.427	3.741 ± 0.267	0.193 ± 0.001	5.971 ± 1.524	11.663 ± 2.711	8.817 ± 2.305	1.430 ± 0.315	9.416 ± 0.394	BDL	4.955 ± 0.689	BDL	6.428 ± 1.724
o,p'-DDD	BDL	BDL	BDL	BDL	6.282 ± 1.350	BDL	BDL	0.902 ± 0.050	BDL	BDL	BDL	BDL	2.569 ± 0.676
p,p'-DDD	BDL	10.913 ± 2.142	14.805 ± 2.930	BDL	15.047 ± 1.810	8.840 ± 2.559	4.509 ± 0.927	2.302 ± 0.010	1.943 ± 0.319	BDL	0.394 ± 0.041	BDL	8.795 ± 1.633
o,p'-DDE	6.624 ± 1.308	BDL	BDL	0.512 ± 0.001	BDL	BDL	BDL	0.704 ± 0.141	BDL	BDL	BDL	BDL	BDL
p,p'-DDE	5.493 ± 1.212	BDL	BDL	2.356 ± 0.011	BDL	BDL	BDL	1.237 ± 0.129	BDL	BDL	BDL	BDL	2.937 ± 0.550

BDL = below detection limits, n = 3, mean ± standard deviation, DW = dry weight

(p < 0.01) in the range 0.511 to 0.912. The highest correlation value of 0.912 was obtained for Sites 1 and 3, the lowest value of 0.511 was obtained for Sites 6 and 11. The levels detected for dieldrin, endosulfan sulphate, β-endosulfan, lindane, methoxychlor, p,p'-DDT and o,p'-DDE at Sites 1 and 3 (Table 5) were slightly lower than the WHO guidelines (Table 7) for daily intake of drinking water (IUPAC 2003). Aldrin was not detected in water from any of the sampling sites, but its metabolite dieldrin was detected at all the sampling sites, with the highest levels at Sites 10 and 14, respectively (Table 5), which were higher than the WHO guidelines for daily intake of drinking water (Table 7). Heptachlor-epoxide detected at Sites 9 and 11 gave levels higher than the WHO guidelines (IUPAC 2003). The residue levels of α-endosulfan, heptachlor, o,p'-DDT, o,p'-DDD and o,p'-DDE were below the detection limits (BDL) in February. Total DDT residue levels given as (Σ DDT) in Kericho upper Nyando Subcatchment is lower than the WHO limit in drinking water (Table 7). In May, the pesticide concentrations detected in water samples (Table 6) from the Upper Subcatchment showed strong positive bivariate Pearson correlation coefficients (p < 0.01) in the range 0.507 to 0.993, with the highest correlation (0.993) being at Sites 4 and 9, and the lowest value of 0.507 obtained at Sites 1 and 7, respectively. Methoxychlor was detected at highest concentration at Site 9 followed by endosulfan sulphate at Site 11 (Table 6). However these concentrations are lower than the WHO guidelines for drinking water (Table 7). Dieldrin was detected in the middle and lower reaches of the river with the highest concentrations at Site 14 in May.

Pesticide residue levels detected in sediments in February were considerably higher than those found in water (Table 5). The sediment concentrations showed strong positive Pearson correlation coefficients (p < 0.01) in the range 0.576 to 0.999, with the highest correlation (0.999) obtained at Sites 1 and 9, whereas the lowest value (0.576) was obtained at Sites 7 and 14, respectively. The highest residue levels in sediments (Table 6) were detected for methoxychlor at Sites 13 and 14, respectively. During the dry season, levels of α-endosulfan were below the detection limit in all the sediment samples. The concentrations of dieldrin, endosulfan sulphate and endrin were generally lower compared with those of lindane at various sites. The pesticides concentrations detected in the sediment samples, showed strong positive bivariate Pearson correlation coefficients (p < 0.01) in the range of 0.580 to 0.997 in May. The highest correlation value of 0.997 was obtained for Sites 4 and 7 and the lowest value of 0.580 was obtained for Sites 3 and 12, respectively. The highest concentration was detected for methoxychlor from Site 4 followed by lindane at Site 12, whereas dieldrin was highest at Site 6 (Table 6).

The concentrations detected in weed samples in February showed strong positive bivariate Pearson correlation coefficients (p < 0.01) in the range 0.548 to 0.963. The highest correlation value of 0.963 was obtained at Sites 3 and 14, and the lowest value of 0.548 was obtained at Sites 4 and 5, respectively. The highest pesticides residue concentrations were detected for methoxychlor at Site 8. This

Table 6: Pesticide residue levels in water (µg l^{-1}), sediment (µg kg^{-1}, DW) and weeds (µg kg^{-1}, DW) from Kericho-Upper Nyando in May

Site pesticide	1	3	4	5	6	7	8	9	10	11	12	13	14
water													
aldrin	BDL	BDL	BDL	BDL	BDL	0.045 ± 0.002	BDL	BDL	BDL	BDL	BDL	BDL	0.025 ± 0.005
dieldrin	BDL	BDL	BDL	BDL	0.040 ± 0.016	0.025 ± 0.009	0.029 ± 0.002	0.040 ± 0.005	0.035 ± 0.012	0.035 ± 0.003	0.032 ± 0.003	0.037 ± 0.004	0.041 ± 0.006
endosulfan S	0.053 ± 0.001	0.028 ± 0.003	BDL	0.038 ± 0.005	0.061 ± 0.004	0.305 ± 0.003	0.018 ± 0.001	0.307 ± 0.047	BDL	0.369 ± 0.031	0.005 ± 0.001	0.053 ± 0.002	0.299 ± 0.027
α-endosulfan	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.010 ± 0.001
β-endosulfan	BDL	BDL	BDL	BDL	BDL	0.036 ± 0.050	0.018 ± 0.001	0.042 ± 0.001	0.008 ± 0.001	BDL	0.006 ± 0.002	0.009 ± 0.001	0.016 ± 0.006
endrin	0.047 ± 0.003	BDL	BDL	BDL	BDL	0.147 ± 0.004	0.038 ± 0.001	0.013 ± 0.002	0.011 ± 0.002	0.006 ± 0.001	0.028 ± 0.001	BDL	BDL
heptachlor	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
heptachlor-epoxide	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.008 ± 0.001	BDL	0.040 ± 0.002	BDL	BDL
lindane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
methoxychlor	0.042 ± 0.004	0.033 ± 0.004	0.864 ± 0.068	0.026 ± 0.001	0.031 ± 0.001	0.017 ± 0.002	0.382 ± 0.007	4.050 ± 0.138	1.190 ± 0.016	0.17 ± 0.001	0.285 ± 0.074	0.403 ± 0.028	0.799 ± 0.013
o,p'-DDT	0.017 ± 0.001	BDL	0.026 ± 0.003	BDL	BDL	0.025 ± 0.019	0.016 ± 0.004	BDL	BDL	BDL	BDL	BDL	0.025 ± 0.005
p,p'-DDT	0.054 ± 0.002	BDL	0.062 ± 0.003	0.058 ± 0.001	0.051 ± 0.019	0.065 ± 0.008	0.081 ± 0.008	0.159 ± 0.036	0.018 ± 0.001	0.053 ± 0.018	0.045 ± 0.008	0.035 ± 0.009	0.128 ± 0.004
o,p'-DDD	0.086 ± 0.003	BDL	BDL	0.009 ± 0.002	BDL	0.326 ± 0.017	0.015 ± 0.005	0.016 ± 0.010	0.003 ± 0.001	0.008 ± 0.001	BDL	BDL	0.025 ± 0.006
p,p'-DDD	0.005 ± 0.002	BDL	0.013 ± 0.004	BDL	0.029 ± 0.002	0.050 ± 0.015	0.031 ± 0.002	0.031 ± 0.005	0.009 ± 0.001	0.033 ± 0.005	0.027 ± 0.003	0.014 ± 0.004	0.028 ± 0.003
o,p'-DDE	0.005 ± 0.001	BDL	BDL	BDL	0.005 ± 0.002	BDL	BDL	0.009 ± 0.002	BDL	0.008 ± 0.001	BDL	BDL	BDL
p,p'-DDE	0.130 ± 0.004	BDL	0.085 ± 0.004	0.057 ± 0.001	0.062 ± 0.003	0.029 ± 0.003	0.093 ± 0.003	0.095 ± 0.003	BDL	0.053 ± 0.001	0.092 ± 0.02	0.041 ± 0.003	0.097 ± 0.017
Sediment													
aldrin	10.793 ± 1.203	BDL	11.140 ± 1.627	19.878 ± 2.658	7.618 ± 0.946	BDL	BDL	4.456 ± 1.780	BDL	BDL	BDL	12.565 ± 2.259	11.935 ± 2.798
dieldrin	10.271 ± 1.859	8.182 ± 1.697	10.973 ± 2.826	BDL	16.760 ± 3.808	13.053 ± 4.227	7.747 ± 2.257	0.483 ± 0.257	10.041 ± 2.766	12.559 ± 3.562	0.207 ± 0.084	0.145 ± 0.035	0.210 ± 0.016
endosulfan S	BDL	1.365 ± 0.207	3.266 ± 0.324	BDL	3.075 ± 0.252	3.315 ± 0.384	1.173 ± 0.162	2.370 ± 0.528	1.601 ± 0.432	6.611 ± 0.882	3.035 ± 0.032	9.343 ± 1.716	0.831 ± 0.110
α-endosulfan	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
β-endosulfan	BDL	0.256 ± 0.096	0.075 ± 0.010	BDL	BDL	1.563 ± 0.533	3.964 ± 0.277	9.397 ± 0.896	BDL	0.299 ± 0.029	3.892 ± 0.336	BDL	BDL
endrin	1.496 ± 0.212	BDL	0.063 ± 0.026	3.154 ± 0.239	1.476 ± 0.364	0.443 ± 0.172	BDL	BDL	4.540 ± 0.787	7.869 ± 1.327	1.159 ± 0.086	BDL	1.095 ± 0.086
heptachlor	BDL	1.284 ± 0.298	BDL	BDL	BDL	BDL	1.166 ± 0.098	BDL	BDL	BDL	BDL	BDL	1.311 ± 0.311
Heptachlor-epoxide	BDL	BDL	BDL	1.315 ± 0.167	BDL	2.135 ± 0.343	BDL	4.147 ± 0.416	1.026 ± 0.414	1.026 ± 0.157	2.372 ± 0.528	BDL	0.756 ± 0.094
lindane	0.023 ± 0.018	0.240 ± 0.059	0.029 ± 0.007	9.171 ± 1.618	4.239 ± 1.695	0.030 ± 0.014	8.163 ± 0.568	16.115 ± 1.600	9.278 ± 1.257	8.185 ± 0.400	23.201 ± 3.114	0.025 ± 0.006	11.933 ± 2.662
methoxychlor	131.332 ± 4.799	53.557 ± 4.848	284.281 ± 3.108	59.610 ± 3.803	24.027 ± 2.951	132.217 ± 3.258	22.757 ± 2.783	189.614 ± 5.172	30.134 ± 3.134	2.011 ± 0.209	22.383 ± 4.271	21.526 ± 4.809	58.536 ± 3.472
o,p'-DDT	3.391 ± 0.580	0.809 ± 0.167	BDL	BDL	BDL	BDL	BDL	BDL	1.308 ± 0.303	2.441 ± 0.645	BDL	BDL	4.296 ± 0.401
p,p'-DDT	6.980 ± 0.774	5.999 ± 0.174	5.919 ± 0.259	5.677 ± 0.909	4.956 ± 0.142	4.205 ± 1.622	2.612 ± 0.769	11.903 ± 2.641	4.344 ± 1.182	5.714 ± 1.467	4.575 ± 0.738	6.251 ± 1.672	3.248 ± 1.634
o,p'-DDD	7.526 ± 0.860	0.591 ± 0.042	0.384 ± 0.053	3.656 ± 1.029	0.585 ± 0.125	BDL	0.567 ± 0.092	BDL	BDL	5.653 ± 0.943	9.215 ± 1.535	BDL	3.172 ± 0.253
p,p'-DDD	3.147 ± 0.251	0.683 ± 0.043	0.504 ± 0.116	0.050 ± 0.001	1.094 ± 0.140	2.101 ± 0.106	0.072 ± 0.004	0.029 ± 0.004	1.357 ± 0.446	BDL	4.214 ± 0.204	1.320 ± 0.352	4.554 ± 0.640
o,p'-DDE	2.146 ± 0.224	BDL	2.403 ± 0.291	0.865 ± 0.104	BDL	BDL	1.903 ± 0.189	6.135 ± 0.316	2.837 ± 0.416	BDL	8.358 ± 0.804	BDL	BDL
p,p'-DDE	12.167 ± 1.739	5.341 ± 0.591	4.873 ± 1.280	6.502 ± 0.647	3.372 ± 0.549	4.072 ± 0.252	6.898 ± 0.162	10.279 ± 1.556	4.761 ± 1.122	BDL	4.515 ± 0.753	BDL	5.002 ± 0.386
Weeds													
aldrin	7.843 ± 1.239	BDL	BDL	BDL	BDL	BDL	10.999 ± 0.479	BDL	BDL	BDL	BDL	BDL	BDL
dieldrin	9.477 ± 1.088	3.346 ± 0.209	6.02 ± 1.311	9.933 ± 1.078	9.012 ± 1.413	7.436 ± 0.268	8.459 ± 1.177	9.631 ± 4.035	6.474 ± 0.632	4.375 ± 0.020	3.417 ± 0.491	3.737 ± 0.003	6.622 ± 0.360
endosulfan S	BDL	3.335 ± 0.111	BDL	3.083 ± 1.315	BDL	5.246 ± 1.441	9.612 ± 1.539	4.807 ± 1.125	2.249 ± 0.848	5.054 ± 0.605	2.231 ± 0.976	BDL	BDL
α-endosulfan	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
β-endosulfan	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
endrin	BDL	BDL	BDL	7.425 ± 1.297	BDL	BDL	2.628 ± 0.329	1.075 ± 0.252	48.453 ± 1.709	6.669 ± 1.739	15.061 ± 1.591	5.358 ± 1.393	6.205 ± 1.365
heptachlor	BDL	BDL	BDL	6.546 ± 3.400	BDL	BDL	BDL	BDL	16.558 ± 2.366	BDL	BDL	BDL	BDL
Heptachlor-epoxide	1.935 ± 1.040	4.939 ± 0.781	5.785 ± 0.985	2.158 ± 3.036	BDL	6.270 ± 0.646	7.913 ± 0.777	4.077 ± 1.410	4.816 ± 0.07	6.116 ± 1.694	4.812 ± 0.687	9.137 ± 1.167	6.048 ± 0.810
lindane	6.585 ± 1.357	7.769 ± 0.307	5.160 ± 0.554	3.010 ± 0.043	BDL	5.109 ± 0.126	6.841 ± 1.237	4.942 ± 0.586	1.249 ± 0.063	3.785 ± 1.565	4.251 ± 0.312	2.713 ± 0.949	4.816 ± 0.709
methoxychlor	88.339 ± 6.466	99.691 ± 6.909	44.368 ± 0.531	60.781 ± 5.064	BDL	50.967 ± 4.322	37.077 ± 2.179	21.813 ± 2.489	59.372 ± 2.790	93.086 ± 7.037	19.610 ± 3.507	43.008 ± 8.561	43.008 ± 0.561
o,p'-DDT	BDL	1.769 ± 0.008	BDL	BDL	0.458 ± 0.001	6.302 ± 2.324	BDL	BDL	BDL	BDL	BDL	BDL	BDL
p,p'-DDT	7.972 ± 1.201	BDL	3.522 ± 0.299	1.485 ± 1.498	4.669 ± 1.592	6.881 ± 0.422	5.591 ± 0.103	2.827 ± 0.244	11.274 ± 3.022	2.822 ± 0.163	10.613 ± 3.350	18.291 ± 3.719	BDL

Table 6: (cont.)

Site pesticide	1	3	4	5	6	7	8	9	10	11	12	13	14
o,p'-DDD	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
p,p'-DDD	5.826 ± 0.765	8.518 ± 1.342	1.143 ± 0.233	BDL	BDL	3.095 ± 1.451	6.444 ± 1.183	3.555 ± 2.003	17.865 ± 0.455	BDL	BDL	BDL	BDL
o,p'-DDE	BDL	BDL	BDL	BDL	BDL	5.012 ± 0.872	15.241 ± 3.659	BDL	45.996 ± 3.571	9.706 ± 3.873	BDL	BDL	BDL
p,p'-DDE	BDL	7.252	BDL	BDL	2.536 ± 0.181	BDL	BDL	3.964 ± 4.937	BDL	BDL	BDL	5.211 ± 3.190	5.211 ± 3.190

BDL = below detection limits, n = 3, mean ± standard deviation, DW = dry weight

Table 7: Pesticide level guidelines (µg l^{-1}) for drinking water for some organisations

Pesticide	WHO	EPA	Australia
Aldrin	0.03	NC	0.01
Dieldrin	0.03	NC	NC
DDT	2	0.2	0.06
Lindane	2	0.2	0.05
Methoxychlor	20	40	0.02
Endrin	NC	2	NC
Heptachlor	0.03	0.4	0.05
Heptachlor-epoxide	0.03	0.2	0.05
Endosulfan	NC	NC	0.05

Source: IUPAC 2003, NC = Not classified

was followed by aldrin at the Site 1, whereas the concentrations of α-endosulfan and heptachlor were below the detection limits in all the sites (Table 5). Generally the pesticides levels detected in weed samples were intermediate in magnitude between those of water and sediments (Table 5). The concentrations detected in weeds in May showed strong positive bivariate Pearson correlation coefficients (p < 0.01) in the range 0.577 to 0.987, with the highest (0.987) at Sites 1 and 4 and the lowest (0.577) at Sites 4 and 10, respectively. The highest concentration detected for methoxychlor in weed samples was at Site 3, followed by that of p,p'-DDT at Site 13. The α- and β-endosulfan and o,p'-DDD concentrations were below the detection limits in all the samples analysed (Table 6)

Seasonal variations in pesticide residue levels in the Nandi- Lower Nyando Subcatchment area

The mean concentrations for organochlorine pesticide residue levels in water, sediments and weeds in the dry and wet seasons in the Nandi-Lower Nyando area are shown in Tables 8 and 9. The sixteen pesticides residues monitored during the dry seasons showed a high frequency at Sites 33 (Ahero irrigation channel), with 68.8% of pesticides residue levels detected in water samples, 94% for sediments, whereas weed samples at Sites 16 and 17 had a frequency of 50% (Table 8). In wet season, Sites 25 and 33 showed the highest frequency of 75% of pesticides residue levels detection in water samples, whereas sediments were at 81% in Sites 19 and 23 and weeds at 50% at Sites 16, 17, 19 and 23 (Table 8).

Most of the pesticides residue levels detected in dry season were below the WHO guidelines for the daily intake for drinking water (Table 7), except for dieldrin whose levels were of concern (Table 8). The Lower Subcatchment area showed slightly higher pesticide residue levels in water (Table 8) than the Upper in February (Table 5). Total DDT residue levels in Nandi-Lower Nyando Subcatchment area were higher than the WHO limit. The pesticides levels detected in water samples in February showed strong positive bivariate Pearson correlation coefficients (p < 0.05) in the range 0.525 to 0.993, with the highest correlation obtained at Sites 15 and 17 and the lowest (0.525) at Sites 15 and 21, respectively. The Lower Subcatchment showed higher concentrations in water (Table 9) than the upper area (Table 6) in May, with a strong positive bivariate Pearson correlation coefficient

Table 8: Pesticide residue levels in water (µg l^{-1}), sediment (µg kg^{-1}, DW) and weeds (µg kg^{-1}, DW) from Nandi-Lower Nyando in February

Site pesticide	15	16	17	18	19	21	22	23	25	26	27	30	33
Water													
aldrin	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
dieldrin	0.219 ± 0.011	0.178 ± 0.020	0.181 ± 0.022	0.124 ± 0.002	0.136 ± 0.003	0.192 ± 0.015	0.353 ± 0.062	0.320 ± 0.075	0.080 ± 0.019	0.413 ± 0.011	0.417 ± 0.035	BDL	0.336 ± 0.032
endosulfan S	0.016 ± 0.002	0.019 ± 0.070	0.026 ± 0.032	0.013 ± 0.002	0.108 ± 0.019	0.067 ± 0.015	0.114 ± 0.032	0.026 ± 0.014	0.029 ± 0.001	0.031 ± 0.001	0.029 ± 0.001	BDL	0.009 ± 0.001
α-endosulfan	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
β-endosulfan	BDL	BDL	BDL	BDL	0.026 ± 0.002	0.168 ± 0.013	0.210 ± 0.032	0.126 ± 0.001	BDL	BDL	BDL	BDL	0.040 ± 0.004
endrin	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.023 ± 0.008
heptachlor	0.010 ± 0.003	0.013 ± 0.006	0.011 ± 0.006	0.013 ± 0.004	BDL	0.012 ± 0.005	0.026 ± 0.002	0.013 ± 0.006	0.091 ± 0.006	0.013 ± 0.004	BDL	BDL	0.140 ± 0.004
heptachlor-epoxide	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.060 ± 0.004
lindane	0.066 ± 0.001	0.074 ± 0.010	0.050 ± 0.002	0.044 ± 0.003	0.025 ± 0.004	0.056 ± 0.004	0.054 ± 0.009	0.058 ± 0.003	0.033 ± 0.002	0.056 ± 0.004	0.051 ± 0.003	BDL	0.039 ± 0.001
methoxychlor	0.044 ± 0.002	BDL	0.036 ± 0.001	BDL	0.043 ± 0.003	0.021 ± 0.001	BDL	0.040 ± 0.009	BDL	0.048 ± 0.002	0.044 ± 0.008	BDL	0.032 ± 0.004
o,p'-DDT	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
p,p'-DDT	0.097 ± 0.009	0.085 ± 0.005	0.066 ± 0.020	BDL	0.019 ± 0.005	0.018 ± 0.002	0.027 ± 0.007	0.013 ± 0.009	0.043 ± 0.006	0.061 ± 0.006	0.063 ± 0.004	BDL	0.014 ± 0.061
o,p'-DDD	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
p,p'-DDD	0.122 ± 0.004	0.085 ± 0.015	0.092 ± 0.014	0.056 ± 0.018	0.073 ± 0.003	BDL	0.119 ± 0.070	0.126 ± 0.032	0.031 ± 0.002	0.167 ± 0.019	0.168 ± 0.013	BDL	0.088 ± 0.040
o,p'-DDE	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
p,p'-DDE	0.010 ± 0.004	0.015 ± 0.015	0.019 ± 0.001	0.022 ± 0.008	0.087 ± 0.001	0.024 ± 0.003	0.019 ± 0.007	0.013 ± 0.002	0.031 ± 0.002	0.067 ± 0.019	0.017 ± 0.013	BDL	0.088 ± 0.040
Sediment													
aldrin	0.039 ± 0.009	4.219 ± 1.082	2.548 ± 0.550	0.838 ± 0.053	1.611 ± 0.090	0.015 ± 0.006	BDL	BDL	3.127 ± 0.862	0.292 ± 0.010	0.016 ± 0.008	BDL	0.043 ± 0.535
dieldrin	7.151 ± 1.318	0.153 ± 0.036	0.314 ± 0.188	1.775 ± 0.288	8.232 ± 1.278	0.826 ± 0.213	1.624 ± 0.383	0.346 ± 0.037	0.193 ± 0.007	1.457 ± 0.062	0.037 ± 0.007	0.407 ± 0.020	0.324 ± 0.0169
endosulfan S	2.063 ± 0.038	4.129 ± 0.054	3.141 ± 0.912	1.798 ± 0.140	0.463 ± 0.053	1.244 ± 0.014	4.657 ± 0.793	0.065 ± 0.041	0.189 ± 0.013	1.705 ± 0.851	BDL	BDL	6.419 ± 0.760
α-endosulfan	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
β-endosulfan	0.426 ± 0.039	0.036 ± 0.006	0.018 ± 0.001	BDL	1.874 ± 0.438	10.502 ± 0.800	0.013 ± 0.001	BDL	0.360 ± 0.070	0.083 ± 0.006	BDL	BDL	1.087 ± 0.011
endrin	0.902 ± 0.114	0.320 ± 0.156	BDL	0.361 ± 0.072	0.048 ± 0.007	BDL	0.295 ± 0.086	0.192 ± 0.008	0.537 ± 0.056	0.298 ± 0.124	BDL	BDL	2.974 ± 0.300
heptachlor	BDL	1.154 ± 0.063	0.172 ± 0.006	1.718 ± 0.194	0.276 ± 0.051	0.420 ± 0.156	BDL	BDL	BDL	BDL	BDL	BDL	0.699 ± 0.065
Heptachlor-epoxide	BDL	3.939 ± 0.466	0.406 ± 0.009	BDL	0.188 ± 0.016	1.888 ± 0.125	0.661 ± 0.073	0.872 ± 0.104	0.384 ± 0.116	1.090 ± 0.172	BDL	0.069 ± 0.018	0.900 ± 0.077
lindane	3.032 ± 0.581	6.555 ± 0.825	0.813 ± 0.142	0.050 ± 0.006	0.802 ± 0.142	2.925 ± 0.081	4.645 ± 0.564	0.871 ± 0.076	4.582 ± 0.776	0.822 ± 0.145	0.016 ± 0.001	7.403 ± 0.694	10.619 ± 0.595
methoxychlor	278.327 ± 1.014	66.018 ± 4.486	68.695 ± 7.552	77.264 ± 2.601	98.627 ± 3.654	49.791 ± 2.479	0.797 ± 0.042	53.584 ± 2.184	3.024 ± 0.084	27.975 ± 5.553	10.526 ± 2.011	4.097 ± 0.139	8.640 ± 0.759
o,p'-DDT	1.084 ± 0.155	BDL	BDL	BDL	0.268 ± 0.079	0.179 ± 0.011	0.182 ± 0.023	0.290 ± 0.004	1.276 ± 0.030	BDL	BDL	BDL	1.117 ± 0.010
p,p'-DDT	3.097 ± 0.157	4.378 ± 0.544	1.871 ± 0.069	1.497 ± 0.405	0.278 ± 0.030	1.560 ± 0.295	2.956 ± 0.236	0.925 ± 0.088	1.219 ± 0.046	2.008 ± 0.129	1.680 ± 0.200	3.857 ± 0.377	1.927 ± 0.085
o,p'-DDD	0.920 ± 0.003	1.157 ± 0.011	0.313 ± 0.021	0.156 ± 0.015	0.839 ± 0.163	0.488 ± 0.004	0.640 ± 0.068	0.638 ± 0.055	0.444 ± 0.065	0.317 ± 0.007	0.464 ± 0.071	BDL	3.062 ± 0.086
p,p'-DDD	0.920 ± 0.003	1.157 ± 0.012	0.313 ± 0.021	0.156 ± 0.015	0.839 ± 0.163	0.488 ± 0.004	0.640 ± 0.068	0.638 ± 0.055	0.444 ± 0.065	0.317 ± 0.07	0.464 ± 0.071	BDL	3.062 ± 0.086
o,p'-DDE	BDL	BDL	BDL	BDL	0.427 ± 0.007	BDL	0.252 ± 0.003	BDL	BDL	0.249 ± 0.055	BDL	0.433 ± 0.062	0.951 ± 0.052
p,p'-DDE	3.145 ± 0.330	3.918 ± 0.814	BDL	2.711 ± 0.674	0.585 ± 0.015	1.775 ± 0.291	0.904 ± 0.054	BDL	0.441 ± 0.060	1.023 ± 0.016	BDL	4.139 ± 0.344	3.379 ± 0.649
Weeds													
aldrin	BDL	3.067 ± 0.014	0.911 ± 0.402	0.996 ± 0.105	BDL	0.067 ± 0.010	7.917 ± 1.409	7.095 ± 1.237	2.883 ± 0.417	BDL	BDL	BDL	BDL
dieldrin	5.366 ± 0.098	6.114 ± 1.911	1.993 ± 0.004	6.102 ± 0.194	32.963 ± 4.099	2.178 ± 1.101	BDL	BDL	5.313 ± 1.146	BDL	31.750 ± 1.493	BDL	BDL
endosulfan S	3.865 ± 0.325	4.970 ± 0.412	0.256 ± 0.097	BDL	BDL	0.170 ± 0.011	1.567 ± 0.314	8.140 ± 0.417	BDL	BDL	2.195 ± 0.294	BDL	BDL
α-endosulfan	BDL	BDL	BDL	BDL	BDL	BDL	66.149 ± 1.589	17.793 ± 2.947	BDL	BDL	BDL	BDL	BDL
β-endosulfan	BDL	BDL	BDL	BDL	BDL	BDL	4.970 ± 0.412	BDL	BDL	BDL	BDL	BDL	BDL
endrin	BDL	1.567 ± 0.314	1.214 ± 0.041	1.906 ± 0.410	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
heptachlor	BDL	BDL	BDL	BDL	BDL	BDL	BDL	6.105 ± 0.170	BDL	BDL	BDL	BDL	BDL
heptachlor-epoxide	BDL	BDL	BDL	BDL	2.691 ± 0.211	BDL	BDL	37.664 ± 6.635	BDL	BDL	BDL	BDL	BDL
lindane	BDL	2.316 ± 0.131	1.104 ± 0.101	4.996 ± 0.453	2.272 ± 0.205	0.967 ± 0.034	1.567 ± 0.314	8.140 ± 0.417	10.307 ± 1.831	BDL	BDL	BDL	BDL
methoxychlor	10.087 ± 2.925	12.219 ± 1.309	4.787 ± 0.997	7.029 ± 1.972	14.902 ± 3.221	4.614 ± 0.681	6.149 ± 0..589	17.793 ± 2.947	BDL	BDL	7.323 ± 0.907	BDL	BDL
o,p'-DDT	BDL	BDL	BDL	BDL	1.120 ± 0.170	BDL	BDL	BDL	24.612 ± 0.995	BDL	BDL	BDL	BDL
p,p'-DDT	28.294 ± 1.010	4.987 ± 0.135	6.190 ± 0.017	4.996 ± 0.453	10.533 ± 0.089	BDL	BDL	BDL	BDL	BDL	17.573 ± 1.344	BDL	BDL
o,p'-DDD	BDL	BDL	BDL	BDL	3.072 ± 0.453	BDL	BDL	BDL	2.104 ± 0.169	BDL	BDL	BDL	BDL
p,p'-DDD	BDL	BDL	BDL	BDL	4.010 ± 0.994	BDL	0.149 ± 1.589	0.793 ± 2.947	BDL	BDL	6.253 ± 1.490	BDL	BDL
o,p'-DDE	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
p,p'-DDE	BDL	2.543 ± 0.162	0.419 ± 0.012	1.223 ± 0.145	BDL	BDL	BDL	BDL	4.800 ± 1.149	BDL	BDL	BDL	BDL

Table 9: Pesticide residue levels in waterep, sediments (µg kg^{-1}, DW) and weeds (µg kg^{-1}, DW) from Nandi-Lower Nyando in May

Pesticide residues site	15	16	17	18	19	21	22	23	25	26	27	30	33
Water													
aldrin	BDL	BDL	BDL	0.021 ± 0.001	BDL	BDL	BDL	BDL	0.011 ± 0.003	0.014 ± 0.003	BDL	BDL	BDL
dieldrin	0.040 ± 0.001	0.045 ± 0.005	BDL	0.051 ± 0.005	0.041 ± 0.005	0.033 ± 0.003	0.042 ± 0.003	0.070 ± 0.015	0.078 ± 0.006	0.046 ± 0.005	0.032 ± 0.001	BDL	0.033 ± 0.007
endosulfan S	0.033 ± 0.002	0.038 ± 0.005	BDL	0.046 ± 0.004	0.036 ± 0.004	0.015 ± 0.001	0.039 ± 0.003	0.023 ± 0.002	0.052 ± 0.011	1.558 ± 0.166	0.027 ± 0.001	BDL	0.021 ± 0.002
α-endosulfan	0.003 ± 0.001	BDL	BDL	0.006 ± 0.001	BDL	BDL	BDL	BDL	0.012 ± 0.001	BDL	BDL	BDL	BDL
β-endosulfan	0.009 ± 0.002	BDL	BDL	BDL	BDL	0.006 ± 0.001	0.040 ± 0.001	0.03 ± 0.006	BDL	0.029 ± 0.002	BDL	BDL	BDL
endrin	BDL	BDL	BDL	BDL	0.027 ± 0.001	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
heptachlor	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
heptachlor-epoxide	0.023 ± 0.003	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.005 ± 0.001	0.012 ± 0.003	BDL	BDL	BDL
lindane	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
methoxychlor	0.016 ± 0.001	0.912 ± 0.071	BDL	0.353 ± 0.020	0.015 ± 0.013	0.246 ± 0.040	0.351 ± 0.057	8.817 ± 0.002	1.088 ± 0.086	0.711 ± 0.002	BDL	BDL	BDL
o,p'-DDT	BDL	BDL	BDL	0.021 ± 0.001	BDL	BDL	BDL	BDL	0.011 ± 0.001	0.014 ± 0.003	BDL	BDL	BDL
p,p'-DDT	0.036 ± 0.004	0.065 ± 0.001	BDL	BDL	0.023 ± 0.008	0.043 ± 0.006	0.032 ± 0.002	0.051 ± 0.006	0.075 ± 0.013	0.031 ± 0.004	0.030 ± 0.003	0.032 ± 0.005	0.0456 ± 0.002
o,p'-DDD	BDL	BDL	BDL	0.021 ± 0.002	BDL	BDL	BDL	0.032 ± 0.001	0.055 ± 0.001	0.014 ± 0.005	BDL	0.035 ± 0.005	BDL
p,p'-DDD	0.016 ± 0.001	0.037 ± 0.008	BDL	0.013 ± 0.003	0.029 ± 0.030	0.026 ± 0.001	0.027 ± 0.002	0.029 ± 0.003	0.044 ± 0.013	0.031 ± 0.002	0.027 ± 0.001	0.034 ± 0.010	BDL
o,p'-DDE	0.014 ± 0.002	BDL	BDL	BDL	BDL	BDL	0.006 ± 0.001	0.009 ± 0.002	0.058 ± 0.002	0.013 ± 0.001	BDL	0.028 ± 0.003	BDL
p,p'-DDE	0.080 ± 0.004	0.018 ± 0.002	BDL	BDL	BDL	BDL	0.019 ± 0.002	0.031 ± 0.002	0.035 ± 0.001	0.044 ± 0.004	BDL	BDL	0.035 ± 0.001
Sediment													
aldrin	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	10.785 ± 2.058	16.048 ± 1.484
dieldrin	23.620 ± 4.810	6.172 ± 1.406	1.384 ± 0.571	0.115 ± 0.013	10.151 ± 1.435	15.454 ± 2.360	22.015 ± 2.350	12.313 ± 2.820	1.557 ± 0.675	0.362 ± 0.072	0.359 ± 0.082	10.316 ± 1.892	15.038 ± 3.821
endosulfan S	3.022 ± 0.167	6.575 ± 0.836	3.146 ± 0.208	1.132 ± 0.188	2.942 ± 0.209	2.029 ± 0.057	1.092 ± 0.116	0.033 ± 0.005	2.032 ± 0.004	3.425 ± 0.557	4.054 ± 0.035	BDL	2.445 ± 0.639
α-endosulfan	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
β-endosulfan	2.137 ± 0.176	BDL	1.128 ± 0.227	BDL	4.131 ± 0.208	42.095 ± 0.817	BDL	BDL	0.319 ± 0.029	1.093 ± 0.147	2.092 ± 0.034	BDL	1.587 ± 0.309
endrin	BDL	BDL	BDL	0.998 ± 0.122	BDL	BDL	0.750 ± 0.082	3.313 ± 0.314	4.650 ± 0.922	1.257 ± 0.231	1.077 ± 0.115	BDL	3.223 ± 0.034
heptachlor	BDL	2.324 ± 0.463	1.065 ± 0.166	1.064 ± 0.166	4.723 ± 1.127	0.783 ± 0.212	BDL	BDL	BDL	BDL	BDL	BDL	2.032
Heptachlor-epoxide	BDL	3.063 ± 0.237	1.247 ± 0.219	BDL	1.310 ± 0.210	2.249 ± 0.367	1.478 ± 0.396	BDL	2.014 ± 0.056	1.267 ± 0.242	BDL	3.182 ± 0.271	3.360 ± 0.380
lindane	0.032 ± 0.017	0.037 ± 0.008	0.030 ± 0.012	0.029 ± 0.013	0.037 ± 0.009	9.407 ± 1.955	BDL	0.037 ± 0.010	0.049 ± 0.001	0.031 ± 0.002	0.052 ± 0.006	10.530 ± 1.871	10.530 ± 0.695
methoxychlor	73.702 ± 7.893	32.798 ± 3.975	25.406 ± 3.350	45.392 ± 7.749	31.313 ± 1.796	34.435 ± 3.389	65.275 ± 5.308	21.146 ± 1.565	44.989 ± 4.323	24.161 ± 3.821	65.754 ± 4.019	1.253 ± 0.314	64.224 ± 5.917
o,p'-DDT	2.050 ± 0.097	BDL	BDL	BDL	0.908 ± 0.024	1.667 ± 0.097	1.266 ± 0.343	3.267 ± 0.359	BDL	BDL	BDL	BDL	BDL
p,p'-DDT	4.185 ± 1.539	3.977 ± 1.261	2.063 ± 0.101	5.911 ± 0.172	1.184 ± 0.197	9.837 ± 1.185	3.619 ± 0.696	3.776 ± 0.507	7.937 ± 1.265	2.699 ± 3.589	0.154 ± 0.013	4.518 ± 0.589	32.172 ± 2.911
o,p'-DDD	5.980 ± 1.275	0.142 ± 0.022	0.140 ± 0.024	0.710 ± 0.053	1.983 ± 0.121	3.950 ± 0.510	6.630 ± 0.940	1.582 ± 0.484	BDL	2.214 ± 0.278	BDL	1.406 ± 0.548	BDL
p,p'-DDD	0.658 ± 0.065	3.158 ± 0.103	1.498 ± 0.574	0.053 ± 0.005	1.475 ± 0.568	1.130 ± 0.202	6.834 ± 0.403	0.123 ± 0.005	3.250 ± 0.310	0.138 ± 0.041	0.179 ± 0.016	BDL	7.815 ± 1.028
o,p'-DDE	BDL	4.747 ± 0.352	BDL	BDL	0.842 ± 0.075	BDL	1.240 ± 0.201	BDL	BDL	3.515 ± 0.439	BDL	2.022 ± 0.230	23.046 ± 3.003
p,p'-DDE	7.995 ± 0.129	7.489 ± 0.741	4.190 ± 0.373	2.259 ± 0.234	4.623 ± 1.024	4.315 ± 0.471	4.315 ± 0.471	BDL	3.136 ± 0.341	6.165 ± 0.279	BDL	5.153 ± 1.378	33.478 ± 4.737
Weeds													
aldrin	2.509 ± 0.064	3.115 ± 0.12 6	BDL	BDL	1.495 ± 0.104	BDL	BDL	4.732 ± 0.069	BDL	BDL	BDL	BDL	5.467 ± 0.279
dieldrin	1.980 ± 0.096	7.031 ± 0.623	BDL	BDL	3.120 ± 0.092	7.172 ± 1.623	3.030 ± 0.657	8.701 ± 1.384	6.628 ± 1.366	9.478 ± 0.820	4.138 ± 0.293	8.556 ± 3.586	5.532 ± 0.959
endosulfan S	1.069 ± 0.089	11.316 ± 0.2610	9.964 ± 1.293	15.897 ± 0.385	9.123 ± 1.521	10.683 ± 2.239	15.989 ± 4.166	BDL	7.785 ± 1.750	5.730 ± 1.157	7.305 ± 2.743	BDL	BDL
α-endosulfan	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
β-endosulfan	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	6.461 ± 2.435	BDL
endrin	BDL	BDL	5.003 ± 1.254	BDL	BDL	BDL	BDL	17.745 ± 1.023	7.361 ± 2.791	BDL	24.708 ± 6.364	13.657 ± 0.065	6.885 ± 1.669
heptachlor	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Heptachlor-epoxide	BDL	5.141 ± 1.110	3.966 ± 0.215	BDL	BDL	8.652 ± 0.089	4.148 ± 0.367	5.346 ± 0.374	6.355 ± 1.204	3.103 ± 0.543	6.910 ± 1.514	7.417 ± 1.812	9.284 ± 0.917
lindane	BDL	8.231 ± 1.451	BDL	BDL	BDL	11.104 ± 1.719	19.088 ± 7.716	14.013 ± 3.247	13.922 ± 4.491	43.307 ± 0.549	17.560 ± 2.918	10.623 ± 1.596	22.021 ± 8.609
methoxychlor	45.083 ± 1.021	34.102 ± 1.231	35.383 ± 2.921	BDL	BDL	44.532 ± 5.879	20.346 ± 0.889	27.407 ± 10.932	49.238 ± 2.487	41.492 ± 8.302	77.279 ± 8.661	10.509 ± 2.274	62.934 ± 8.099
o,p'-DDT	BDL	BDL	BDL	BDL	BDL	BDL	BDL	16.947 ± 5.904	BDL	BDL	BDL	BDL	BDL

Table 9: (cont.)

Pesticide residues site	15	16	17	18	19	21	22	23	25	26	27	30	33
p,p'-DDT	BDL	9.058 ± 0.664	BDL	BDL	BDL	9.860 ± 6.135	6.462 ± 11.921	BDL	23.564 ± 5.164	38.025 ± 1.959	10.394 ± 2.403	10.570 ± 2.577	15.200 ± 5.179
o,p'-DDD	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	2.180 ± 0.796	BDL	BDL	BDL	5.298 ± 3.100
p,p'-DDD	0.564 ± 0.064	BDL	BDL	0.622 ± 0.094	BDL	16.965 ± 2.945	BDL	5.776 ± 0.076	17.069 ± 3.569	BDL	14.778 ± 0.728	4.387 ± 0.874	7.106 ± 2.861
o,p'-DDE	BDL	BDL	BDL	BDL	BDL	8.403 ± 0.991	59.567 ± 7.424	17.395 ± 6.395	2.850 ± 0.897	BDL	BDL	BDL	BDL
p,p'-DDE	1.009 ± 0.009	9.341 ± 1.443	BDL	BDL	BDL	18.553 ± 1.661	BDL	BDL	BDL	BDL	BDL	BDL	BDL

BDL = below detection limits, $n = 3$, mean ± standard deviation, DW = dry weight

($p < 0.01$) varying from 0.813 at Sites 16 and 25 to 0.998 at Sites 15 and 33. Higher concentrations of methoxychlor were detected at Sites 16 and 25 (Table 9). However, these concentrations are lower than the WHO guidelines for drinking water (Table 7). Dieldrin and endosulfan sulphate were detected at all sampling sites, except at Site 30 (Table 9). The highest dieldrin concentration was detected at Site 17, whereas endosulfan sulphate was highest at Site 26 (Table 9), all the levels falling above the WHO guidelines of daily intake for drinking water (IUPAC 2003).

For sediment samples taken in February, methoxychlor, β-endosulfan and lindane were detected at high concentrations (Table 8), and all the levels showed strong positive bivariate Pearson correlation coefficients ($p < 0.05$) in the range 0.499 (Sites 15 and 33) to 0.999 (Sites 15 and 18). The highest level of methoxychlor was detected at Site 15 (Table 8). In May the residue levels in sediments showed strong positive bivariate Pearson correlation coefficients ($p < 0.01$) in the range 0.532 (Sites 21 and 25) to 0.993 Sites (15 and 22). For aldrin, residue levels were highest in the sediment samples collected at Site 33 (Table 9).

For weed samples taken in February, residue levels showed strong positive bivariate Pearson correlation coefficients ($p < 0.01$) in the range 0.550 (Sites 15 and 16) to 0.939 (Sites 19 and 27). Dieldrin was highest at Site 19 and p,p'-DDT at Site 15, respectively (Table 8). For May, however, the residue concentrations showed strong positive bivariate Pearson correlation coefficients ($p < 0.05$) in the range of 0.578 (at Sites 17 and 23) to 0.949 (Sites 15 and 17). The highest concentration was obtained for methoxychlor at Site 26 (Table 9).

Discussion

Occurrence, distribution and concentrations of organochlorine pesticides varied among sites and between seasons. Frequency of residue levels in water samples in Kericho-Upper Nyando Subcatchment area for both May and February (Tables 6 and 5) was highest in the lower and middle reaches of the river (Sites 14 and 8), respectively. This might be as a result of cultivation on the river bank at the two sites (Table 1). Increased run-off of soil laden with substantial amounts of pesticides from these sites is inevitably finding its way into the river (Abong'o et al. 2014), even though the levels obtained in the water (Table 5) fell below the WHO guidelines for drinking water (Table 7). The low levels might also be associated with less intensive subsistence agricultural activities farther away from the river banks, and reduced clearance of forest cover to give additional arable land. This shows that lower amounts of pesticides had been used in the upper reaches of the river. In February, organochlorine pesticide residues in water samples were generally higher (Table 5) than May (Table 6) especially dieldrin, heptachlor-epoxide and methoxychlor. These pesticides were highest at Sites 6, 11 and 14, respectively. This could be attributed to the location of the sites, being in the middle and lower reaches of the river where subsistence agriculture and sugarcane farming on the river banks are intensive, as well as earlier intense use of the pesticides at these sites (Abong'o et al. 2015a).

In the Nandi-Lower Nyando Subcatchment area, pesticide residue levels detected in water samples in February (Tables 8) were generally higher than those obtained in May (Tables 9), especially dieldrin, heptachlor and heptachlor-epoxide (Sites 27 and 33). These sites (Table 1) are in the upper and lower reaches of the river where tea and rice farming activities have taken place respectively over the years (Abong'o et al. 2015a). Lower pesticide residue levels were detected in May than February and this could be a result of dilution effects on pollutants in river water in the wet season. Total DDT residue levels given as (ΣDDT) obtained in Nandi-Lower Nyando Subcatchment in February (average 2.104 µg l^{-1}) were higher than the WHO limit (2 µg l^{-1}) for water (Table 8). The concentration of total DDT (ΣDDT; 1.345 µg l^{-1}) obtained in Kericho-Upper Nyando Subcatchment (Table 5) was statistically significant, given its restricted use in Kenya (PCPB 1992). Although lower than the WHO guidelines for DDT daily intake of drinking water (2 µg l^{-1}), the levels were more than 6 times higher the USA EPA limit (0.2 µg l^{-1}) recommended standard (Table 7). High levels recorded from Nandi-Lower Nyando area might stem from high turbidity and the presence of particulate matter in the water compared with water from the Kericho-Upper Nyando Subcatchment (Abong'o et al. 2015b), because all the water samples were extracted without filtration.

The pesticide residue levels detected for endosulfan sulphate, β-endosulfan, endrin and lindane were slightly lower than the WHO guidelines for daily intake of drinking water (IUPAC 2003) in the two subcatchment areas. However, these low concentrations become significant considering their magnification through the food chains. Even though some of these pesticide residue levels were present only at very low concentrations in the water, they are hazardous, because some species of aquatic life are known to bioconcentrate them 1 000–fold or more (Murty 1985).

Generally in the dry season, the levels of dieldrin and methoxychlor were higher in sediment sample at Site 15 (Nyando at Ongilo) along the Nandi-Lower Nyando (Table 8), than from the Kericho-Upper Nyando Subcatchment (Table 5). These higher levels could be a result of run-off flow of soil contaminated with the pesticides from tea and sugarcane farms in the Nandi-Lower Nyando Subcatchment into the rivers (Abong'o et al. 2015a). Prior to their ban or restriction in use, the pesticides analysed found wide applications in public health for control of disease vectors and in agriculture for control of crop pests. For sediment samples, aldrin was detected in most samples from Kericho-Upper Nyando Subcatchment area than Nandi-Lower Nyando in the wet season. Sediment samples from Sites 5 and 30 were highly contaminated with aldrin, lindane and methoxychlor. The study by Abong'o et al. (2015a) shows higher levels of aldrin, lindane and methoxychlor in soil samples in May in agricultural farm adjacent to Site 4 that drains to Site 5. The high levels might be attributed to the flow of sediments contaminated with the pesticides from Site 4 to 5. The pesticide residue levels were also detected at reference Site 30 (Abong'o et al. 2015b) where no agricultural activities or human settlements were present during the study period, indicating that some pesticides are deposited along the Nyando River drainage basin after aerial transport. The possible sources are the Nandi and Kericho highlands and the Kano plains where agricultural activities are intensive and are close to the tributaries of Nyando River where relatively large tea, sugar cane, coffee, maize, vegetables and rice farms are located (Abong'o et al. 2014). However local use of pesticides in subsistence agriculture and for control of vector borne diseases in small villages around Nyando River should not be disregarded (Abong'o et al. 2015a).

In sediment samples, the concentrations of dieldrin, endosulfan sulphate and endrin detected were generally lower compared with of lindane at various sites. This could be attributed to equilibrium dynamics in the water/sediment system, as well as absorption by aquatic weeds (Linde 1974). Studies by other researchers have also shown that aldrin and heptachlor concentrations usually remain higher than their converted products (Ayes et al. 1997, Barlez, 2002). In the current study, the concentrations of dieldrin, heptachlor epoxide and endosulfan sulphate were notably higher than for aldrin, heptachlor and endosulfan, respectively, in most samples, indicating earlier use.

A total of three orders and five families of aquatic weed samples were recorded from the Nyando River catchment area. These orders were dominated by the Poles followed by Commelinales and Lamiales, respectively. The species *Cyperus distans* dominated the samples; this was followed by *Cyperus alternifolius, Cyperus rotundus, Eichhornia Crassipes* and *Asystasia gangetica*, respectively. *Eichhornia Crassipes* is only found at Sites 18 and 33 in the lower reaches of the river close to Lake Victoria where pesticides and fertilisers are heavily used on the rice farms (Abong'o et al. 2014). The weed samples had high levels of methoxychlor, aldrin, dieldrin, heptachlor, heptachlor epoxide, lindane and endosulfan sulphate in the Nyando catchment. The *Cyperus distans* was the main weed species found at Sites 3 and 14 with the highest correlation occurring in both the two subcatchment areas in February and May.

Pesticide residues in the samples from the different sites within the two subcatchment areas, show that the occurrences and concentrations of the organochlorine pesticides varied among seasons and between sites. Sites 16 and 17 showed the highest lindane and dieldrin levels in water samples in the dry season. This shows that the Nyando River does not have an effective self cleaning capacity in the downstream sections at Sites 16 and 17, because as the river drains in to the Winam Gulf.

Conclusions

The study documents list and levels of organochlorine pesticide residues detected in water, sediments and aquatic weeds in the Nyando River catchment area. The detection frequency was high during the wet season than in the dry. The frequencies were, however, higher for weed samples than water and much lower than in the sediments.

Water, sediments and aquatic weed samples from the Nandi-Lower Nyando Subcatchment area had higher pesticide concentrations than the Kericho-Upper Nyando section. In the Nyando River catchment area, the water

hyacinth menace has been confined to only the rice growing areas (Sites 18 and 33) and close to the lake, where *Cyperus distans* was the main weed species found.

The pooled results show that various environs of Nyando River are contaminated with all the 16 different organochlorine pesticides, including their metabolites, but at different concentrations and distribution levels. Besides, the analyses showed that the pesticides and their metabolites were generally higher in concentration in sediments and weeds than in water. The Nyando River is mainly contaminated with methoxychlor, dieldrin and endosulfan sulphate probably originating from the various agricultural activities. Pesticides concentrations detected previously in soils from the Nyando River agricultural areas (Abong'o 2015a) were generally higher than those in water, sediments and aquatic weeds. Dieldrin, β-endosulfan, endosulfan sulphate, lindane and methoxychlor were found at higher levels in soil samples. Dieldrin, aldrin, lindane, endosulfan sulphate, were the predominant pesticide pollutants in all matrices analysed. The current study therefore reveals that these compounds, although banned by the Kenya Government and have not been legally imported since 1986 (PCPB 1992; PCPB 2009), are still in use in the Nyando River drainage basin and could be impacting negatively on the ecosystem health of the area.

The results also indicate a greater concern for preservation of aquatic fauna. They also signify that rehabilitation, restoration and management of the lake reservoir is not achievable unless the pollution of rivers draining into the lake is checked and eliminated. High levels of public awareness and education about the dangers of pesticides is recommended.

Acknowledgements — We are grateful to the International Foundation for Science (IFS), which provided the research grant (No. W3982–1); the Higher Education Loans Board (HELB) in Kenya for partial sponsorship and to Mr John Okungu, Project Manager, Lake Victoria Environmental Management Project in Kisumu, who provided the field transport and personnel who assisted in sample and data collection

References

Abong'o DA, Wandiga SO, Jumba IO, Van den Brink PJ, Naziriwo BB, Madadi VO, Wafula GA, Kylin H, Nkedi-Kizza Peter. 2015a**:** Organochlorine pesticides residue levels in soil from the Nyando River catchment. *Kenya African Journal of Physical Sciences* 2: 18–32.

Abong'o DA, Wandiga SO, Jumba IO, Van den Brink PJ, Naziriwo BB, Madadi VO, Wafula GA, Nkedi-Kizza Peter, Kylin H. 2015b. Occurrence, abundance and distribution of benthic macroinvertebrates along Nyando River drainage basin, Kenya. *African Journal of Aquatic Science* 40: 373–392.

Abong'o DA, Wandiga SO, Jumba IO, Madadi VO, Kylin H. 2014. Impacts of pesticides on Human health and environment in the River Nyando catchment, Kenya. *International Journal of Humanities, Arts, Medical Science* 2: 1–14.

Agency for Toxic Substances and Disease Registry (ATSDR). 2005. Toxicological profile for Alpha-, Beta-, Gamma-, and Delta-Hexachlorocyclohexane (Update). Atlanta, GA; U.S. Department of Public Health and Human Services.

Ayas Z, Barlas N, Kolankaya D. 1997. Determination of oragnochlorine pesticide residues in various environments and organisms in Goksu Delta, Turkey. Aquatic Toxicology 39: 171–181.

Barlas NE. 2002. Determination of organochlorine pesticide residues in water and Sediment samples in inner Anatolia in Turkey. *Bulletin of Environmental Contamination and Toxicology* 69: 236–242.

Calamari D, Akech MO, Ochumba PBO. 1995. Pollution of Winam Gulf, Lake Victoria, Kenya: A case study for preliminary risk assessment. *Lake Reservoirs Research and Management* 1: 89–106.

Cox JC 2002. *Sampling for pesticide residue analysis.* In Grant IF and Tingle CCD (Eds), *Ecological monitoring methods for the assessment of pesticide impact in the tropics.* pp 125–147 Natural Resources Institute, Chatham, UK.

Cru Ruud CM. 1995. *Conservation and Management of African Great Lakes; Victoria and its basin: Lake Victoria, Tanganyika and Malawi. UNESCO/IHP-IV Project:* pp 30–39.

European Commission. 1999: Assessing the Controls on Pesticide Residues in Fish Coming From Lake Victoria: Final Report DG24.

Getenga. ZM, Keng'ara FO, Wandiga SO. 2004. Determination of organochlorine pesticide residues in soil and water from river Nyando drainage system within lake Victoria Basin, Kenya. *Bulletin of Environmental Contamination and Toxicology* 72: 335–342.

Kishimba MA, Henry L, Mwavura H, Mmochi AJ, Mihale M, Hellar H. 2004. The status of pesticide pollution in Tanzania. *Talanta* 64: 48–53.

Hill A. 2000. *Quality control procedures for pesticide residue guideline for residue monitoring in the European Union,* 2nd Edn; Document no. SANCO/3103/2000, European Commission.

IUCN. 1992. Wetlands programme. Agricultural Chemicals and Wetlands: In Proceedings of KWWG Seminar on Wetlands in Kenya. National Museums of Kenya, Nairobi; pp 161–166.

IUPAC. 2003. Regulatory Limits For Pesticides Residues in Water. *Pure and Applied Chemistry* 75: 1125–1156.

Kasozi GN, Kiremire BT, Bugennyi FWB, Kirsch NH, Nkedi-Kizza P. 2006. Organochlorine Residues in fish and water samples from Lake Victoria Uganda: *Journal of Environmental quality* 2: 584–589.

Lalah JO, Kaigwara PN, Getenga Z, Mghenyi JM, Wandiga SO. 2001. The major Environmental factors that influence rapid disappearance of pesticides from tropical soil in Kenya. *Toxicological and Environmental Chemistry* 81: 161–197.

LVEMP. 2003. *Lake Victoria Environmental Management Project. Phase 1, Revised Draft Scientific Stocking Report-Progress during LVEMP 1 and challenges for the future.* World Bank, Washington DC.

Linde, C. D. 1994. Physico-chemical properties and environmental fate of Pesticides, *Environmental hazards assessment Program*. California, USA.

Mbabazi S.B. 1998. Levels of lindane in soil plants and selected soil fauna in a sprayed maize agroecosystem: MSc Thesis, Makerere University, Kampala, Uganda.

Murty A.S. 1985. Toxicity of residues to fish volume II CRC Press, Inc p. 143.

Odada EO, Ochola WO, Olago DO. 2009. Drivers of ecosystem change and their impact on human well-being in Lake Victoria basin. *African Journal of Ecology* 47: 46–54.

Orgaram. DA. 1992. Mining Industry, hazardous materials and toxic chemicals. National Environmental Task Force No. 6: pp 71–83.

PCPB (Pest Control Products Board).1992: Annual Report, July 1991/June 1991, © 1992 Government Press, Nairobi, Kenya.

PCPB (Pest Control Products Board). 2009. Annual Report, July 2008/June 2009, © 2009 Government Press, Nairobi, Kenya.

Sentongo J. 1998. Assessment of pollution to Lake Victoria by industrial and Municipal activities in Uganda. PhD Thesis, Chemistry Department, Makerere University, Kampala Uganda.

Shepherd KG, Walsh M, Mugo F, Ong C, van Hansen TS, Swallow B, Awiti A, Hai M. 2000. Improved Land Management in Lake Victoria Basin: Linking Land and Lake, Research and Extension,

Catchment and Lake Basin, First Report of Progress and Results July 1999 to March 2000. Working paper 2000–2. Nairobi: International Centre for Research in Agroforestry.

UNESCO. 1993. Chlorinated biphenols in open ocean waters: sampling, extraction, clean up and instrumental determination.10C Manuals and guides. 27: 20.

USEPA (United States Environmental Protection Agency). 1996. *Method 3510C, Separatory Funnel Liquid–Liquid Extraction* (Revision 3, December, 1996. SW846 CH 4.2.1).

Manuscript received 22 December 2016, revised 9 June 2018, accepted 14 June 2018
Associate Editor: P Oberholster