Contamination of Surface Waters by Obsolete Pesticides Emanating from a Point Source in Coast Region, Tanzania

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This paper reports on the concentrations of organochlorine pesticide residues in water samples collected from 1 – 25 km away from a highly obsolete pesticides contaminated site at Vikuge farm in Coast region -Tanzania. GPC-cleaned extracts analyzed by GC-ECD and confirmed by GC-MS showed the presence of twelve compounds namely *p,p*'-DDT, *o,p*'-DDT, *p,p*'-DDE, *o,p*'-DDE, *p,p*'-DDD, *o,p*'-DDD, pentachloroanisole, α-HCH, β-HCH, γ-HCH, aldrin and dieldrin. The concentrations of total DDT ranged from 819 – 1764 ng/l in pond water, below detection limit (bdl) – 1076 ng/l in river water, and bdl – 572 ng/l in drinking water. The concentrations of total HCHs were up to 23 ng/l in pond water, 1167 ng/l in river water, and 12 ng/l in drinking water. The highest concentrations for other compounds were 29.2 ± 0.1 ng/l for pentachloroanisole, 8 ± 0.7 ng/l for aldrin and 6 ± 0.6 ng/l for dieldrin. There are strong positive correlations in the concentrations of most of the detected compounds suggesting a common source. Some concentrations were higher than the respective maximum residue limits and guidelines for aquatic ecosystems indicating potential risks and concerns for public health and the environment at large.

INTRODUCTION

Most developing countries have large quantities of obsolete pesticides, which are neither usable nor disposable locally. It is estimated that there are about 120,000 tonnes of obsolete pesticides in Africa [1]. Most of the stores in which these toxic wastes are kept are substandard. Improper storage of pesticides often leads to pesticides being released into the environment, where they seep into soil or are dispersed by wind and water. Such spillage or dispersion may cause serious soil, surface water or ground water contamination. When soil and water are contaminated, crops, livestock and other organisms may become affected; and when they are consumed by human beings, health risks may occur [2, 3].

In 2001 high levels of pesticide residues including DDTs and HCHs were detected in soil at an old storage site at Vikuge farm (6^0 47'S, $38^0$52'E) in Coast region, Tanzania. The levels of total DDT and total HCH in soil were up to 282,000 mg/kg dw and 63,400 mg/kg dw, respectively [4, 5]. The source of pollution is from a former storage shed, which was used for temporary storage of about 170 metric tons of pesticides donated by the government of Greece to the government of Tanzania in 1986. After the shed's collapse in 1990, the pesticides were exposed to direct sunlight, wind and rain for about six years before a new store was built and the pesticides were repacked and restored in 1996 [4,5]. Even though the pesticides were collected and stored, the old storage site was still heavily contaminated about five years later. In our continued efforts to assess the extent of contamination caused by these obsolete pesticides [4-7], the current study was aimed at investigating the point source's environs' dispersion of pesticide residues in different types of surface waters such as pond water, river water and drinking (dug well) water to find out whether there is any relationship with that source. The concentrations are then evaluated for indications of potential public health risks.

EXEXPERIMENTAL

Sampling

Water samples were collected in September 2002. The samples were collected from River Chombe, which runs in the south – north direction through the eastern part of Vikuge storage site to the Indian Ocean, at 4, 6, 7, 22, 24 and 25 km north of the old storage site. Drinking water samples were collected from three dug wells at 5 km south and one well at 20 km north. Other water samples were collected from River Ruvu, which is located to the west of the point source at 18 and 20 km northwest, and from a pond at 1 km south (Fig.1).

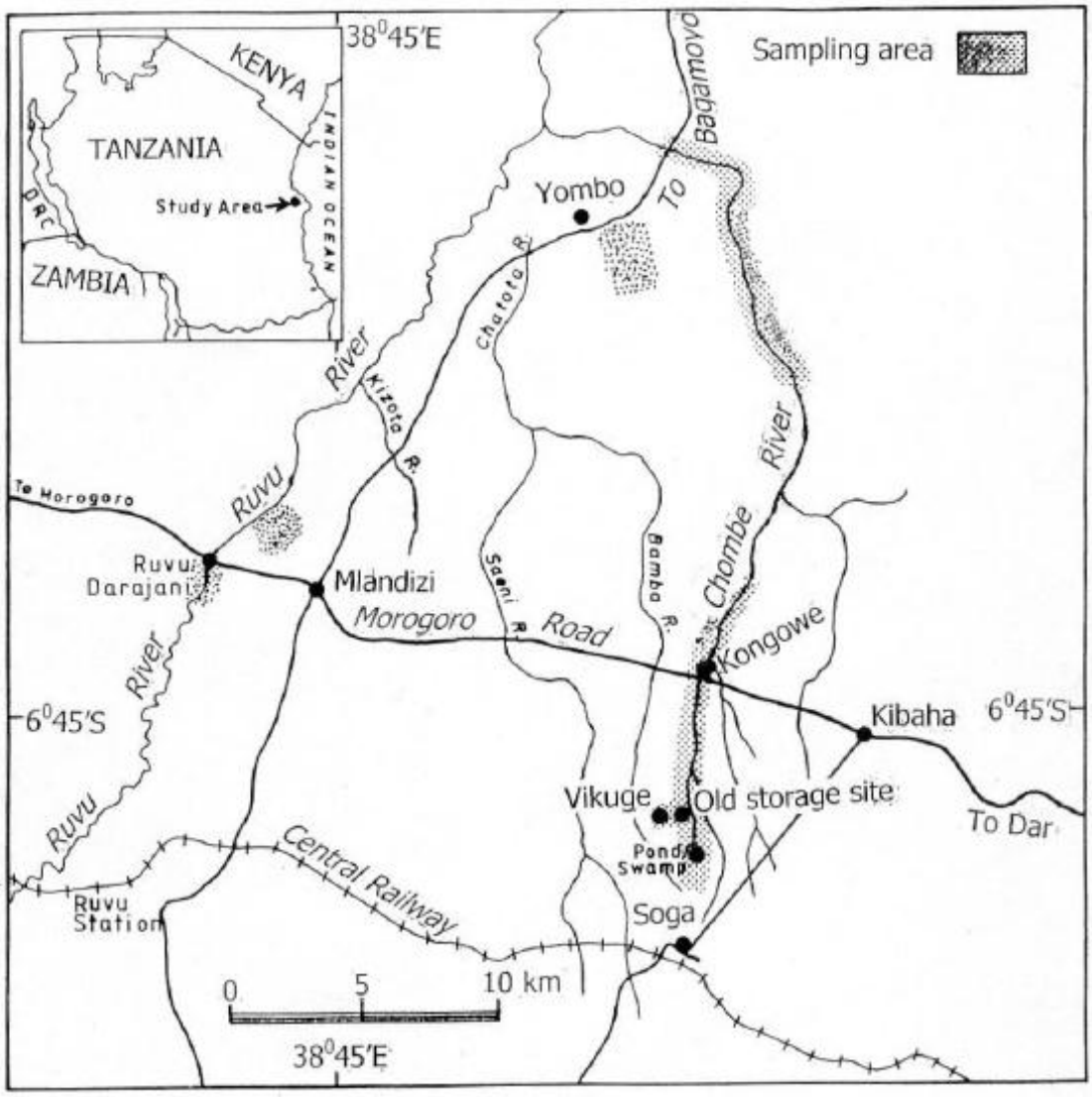


Figure 1: Map showing the study area

Water samples were collected in one litre Teflon stoppered glass sampling bottles, in which sodium chloride (100 g) was added for preservation. The samples were transported to the laboratory and kept in a refrigerator at < 4 ^{o}C until extraction.

Chemicals

All pesticide standards were obtained from Dr. Ehrenstorfer, Augsburg, Germany, and most of them were of over 99% certified purity. Concentrations of standard solutions were corrected for the certified purity of standards if below 99%. Individual stock solutions of pesticides were prepared by dissolving 10-50 mg of each compound in cyclohexane and were stored in glass-stoppered flasks at –18 ^{o}C. Mixed compounds, calibration and measuring standards in cyclohexane were prepared from the stock solutions. Chromatography grade solvents were purchased from Ultrafine Ltd., London. Anhydrous sodium sulphate was obtained from Rochelle Chemicals & Lab Equpment, South Africa. Laboratory glassware was washed with detergents, rinsed with distilled water and acetone, and then dried in an oven at 110 ^{0}C overnight prior to use.

Extraction and clean up

The unfiltered water sample (1 L) was extracted using liquid-liquid extraction (LLE) method [8] with dichloromethane (100 ml, then

50 ml, and finally 50 ml). The combined organic extracts were dried with anhydrous sodium sulphate (15-20 g), filtered, and solvent evaporated using a rotavapor with the water bath at 35 ^{o}C and replaced with cyclohexane (1 ml).

Gel Permeation Chromatography (GPC) clean up of river water and pond water samples extracts was performed using a 50 cm x 1 cm i.d. chromatographic tube, with two adaptors and a six-way valve with a 1 ml sample injector loop and teflon tubing (Pharmacia no SR 10/50, Uppsala, Sweden). Elution was with cyclohexane/ethylacetate (1:1 v/v). The GPC was calibrated using *p,p'*-DDD and *p,p'*-DDE [8]. Pesticides were eluted between the 17–35 ml. During the clean up, the first fraction (0-16 ml) was discarded. The second fraction (17-36 ml) was collected and concentrated for analyses. The column was cleaned with cyclohexane/ethylacetate (1:1 v/v, 20 ml) before injection of the next sample. The solvent of the 17–35 ml fraction was evaporated and replaced with cyclohexane (2 ml) for GC-ECD and GC-MS analyses.

Gas chromatographic analyses

The gas chromatographic (GC) analyses were conducted using a Varian Star 3400 gas chromatograph, equipped with SE-30 and OV-1701 columns (30 m, 0.32 mm i.d., 0.25 μm film thickness, Hewlett Packard), with a ^{63}Ni electron capture detector at the Department of Chemistry, University of Dar es Salaam. Hydrogen was used as both a carrier and make-up gas at a flow rate of 30 ± 1 ml/min. The temperature programme was 90 °C held for 1 min, ramped at 30 °C/min to 180 °C, then ramped at 4 °C/min to 260 °C and held for 12 min. The injector and detector temperatures were 250 °C and 300 °C, respectively. A volume of 2 μl was injected in every run. Measuring standards as well as internal and external standards were injected in the beginning and after every four samples.

Confirmatory analyses were conducted with GC-MS at the Institute of Ecological Chemistry, GSF-National Research Centre for Environment and Health, Munich-Germany. A Fisons 8060 gas chromatograph, coupled to an MD 800 mass selective detector, equipped with an AS 800 autosampler (Fisons Instruments) was employed. A DB-5 capillary column (30 m, 0.32 mm i.d., 0.25 μm film thickness, J&W Scientific USA) was used. The temperature programme was 60 °C held for 1 min, ramped at 12 °C/min to 140 °C, ramped at 5 °C/min to 210 °C and held for 1 min, and then ramped at 12 °C/min to 280 °C and held for 3 min. The carrier gas (helium) was in constant flow mode at a column head pressure of 50 kPa. Splitless injection of a 1 μl volume was carried out at 250 °C injector temperature. The mass spectrometer was operated in an electron ionization mode, quadrupole-MS, with interface temperature of 280 °C, the ion source was at 220 °C. Selected ion monitoring mode with two different m/z for each analyte was used, and the scan mode for all samples was m/z 50 – 500. An internal standard solution (a 10 ng/μl mixture of ^{13}C-labelled HCB, *p,p'*-DDT and *p,p'*-DDE, Dr. Ehrenstorfer, Germany) was added (10 μl) to each of the sample extracts and to the mixtures of calibration standards. The GC/MS was calibrated by means of 5 standard solutions (0.005, 0.05, 0.1, 0.25 and 1 ng/μl for each of the analytes to be quantified). Each analysis was performed in duplicate. A mixture of measuring standards was injected after every three samples.

Identification of analytes was done by comparing the retention times and relative retention times with parathion as internal standard in GC-ECD, and retention times, relative retention times with HCB as internal standard, and mass spectra in GC-MS with those of standards. Quantification of analytes was done by using the peak heights and the internal standards method [9] using two different *m/z* for each analyte.

Analytical quality assurance

A 100 ml aliquot of each solvent was concentrated to 2 ml and used to check the contamination from the reagents used. Two matrix blanks (distilled water) were also conducted. No significant peaks appeared in the chromatograms of the blanks. Recoveries were estimated by spiking the distilled water with pesticide standards at concentrations ranging from 0.01 – 1 μg/ml of each analyte. The average recoveries ± SD (n = 2) were as follows: aldrin 80.2% ± 1.3, dieldrin 79.9% ± 2.9, α-HCH 85.8% ± 3.6, β-HCH 99.3% ± 1.2, γ-HCH 97.9% ± 2, chlorpyriphos 92.3% ± 2.5, *p,p'*-DDE 98.1% ± 1.5, *p,p'*-DDD 80.9% ± 3.2, *p,p'*-DDT 89.6% ± 3.5, fenitrothion 90% ± 3.2, heptachlor 78.3% ± 3.3 and *cis*-chlordane 79.8% ± 2.6. The results were not corrected for recoveries since all were within the normal acceptable range of 70 – 110% [10]. The detection limits were 1.0 ng/l for pentachloroanisole, *p,p*'-DDT, *o,p*'-DDT, *p,p*'-DDD, *o,p*'-DDD, *p,p*'-DDE, and *o,p*'-DDE; and 2.0 ng/l for HCHs (α-, β-, γ-, δ-, and ε-HCH),

heptachlor, *cis*-heptachlor epoxide, *trans*-heptachlor epoxide, oxy-chlordane, *cis*-chlordane, aldrin and dieldrin.

RESULTS AND DISCUSSION

The pesticide residues detected in the water samples were pentachloroanisole, *p,p'*-DDT, *o,p'*-DDT, *p,p'*-DDE, *o,p'*-DDE, *p,p'*-DDD, *o,p'*-DDD, α-HCH, β-HCH, γ-HCH, aldrin and dieldrin.

Distribution of DDT residues

The compounds *o,p*'-DDD, *p,p*'-DDD, *p,p*'-DDE and *p,p*'-DDT were detected in 74% - 90% of the samples, while *o,p*'-DDT and *o,p*'-DDE were detected in 42% and 11% of the samples, respectively. Their concentrations are presented in Table 1.

In the rivers, the highest concentrations of DDT residues (± SD) ranged from 6.3 ± 0.1 ng/l for *p,p*'-DDE to 807 (± 41) ng/l for *p,p*'-DDT and all were found at 20 km NW (River Ruvu). This may be due to the fact that River Ruvu is a big and perennial river that runs through a wide area along the western part of Vikuge and therefore, there may be also inputs of these contaminants due to runoff from different areas where it passes, compared with River Chombe, which is small and seasonal. In pond water, the highest concentrations (± SD) ranged from 4.3 (± 2) ng/l for *o,p*'-DDE, to 1123 (± 41) ng/l for *p,p*'-DDT. These levels were generally higher than the concentrations in the rivers and wells as expected because of the proximity of the pond to the point source and that, unlike river water which flows, pond water is static. In drinking water from dug wells, the highest concentrations (± SD) ranged from 5.2 (± 0.4) ng/l for *p,p*'-DDE to 443 (± 10) ng/l for *p,p*'-DDT (all found at 5 km S). Since the sampling sites are separated from the Vikuge - former storage site by ridges and hills, it seems that wind transport (volatilization) is the most important mechanism involved in the transfer of these semi-volatile pesticide residues from the source.

The mean concentrations of DDT residues in water ± SD (ng/l) were in the order *p,p'*-DDT (273 ± 292) > *o,p'*-DDT (53 ± 100) = *p,p'*-DDD (50 ± 50) > *o,p'*-DDD (6.1 ± 7) > *p,p'*-DDE (3.3 ± 3.3) > *o,p'*-DDE (0.4 ± 1.2). The observed profile is similar to that previously found at the point source for soil [4,5]. These concentrations clearly indicate contamination by technical DDT, which primarily consists of 65–80% *p,p'*-DDT, and 15–21% *o,p'*-DDT [11].

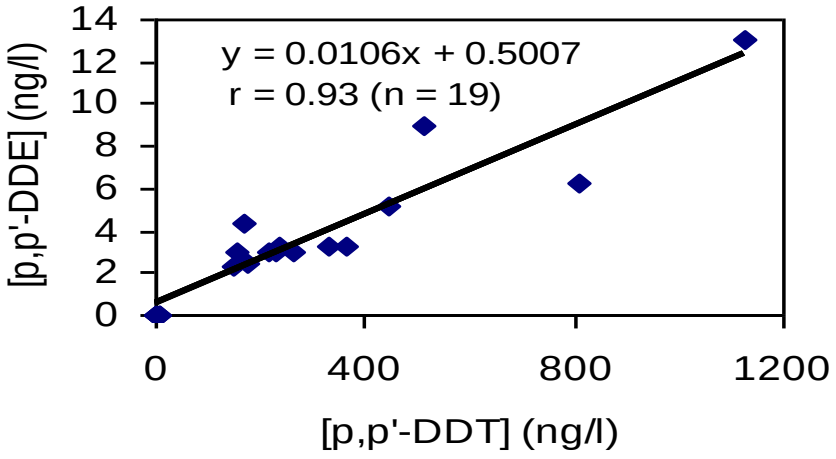
Table 1: Mean concentrations of DDT residues in water (ng/l ± SD, n = 2) analyzed by GC-MS

Distance/ Location	Source	*p,p*'-DDT	*o,p*'-DDT	*p,p*'-DDE	*o,p*'-DDE	*p,p*'-DDD	*o,p*'-DDD	Total DDT	DDE/ DDT
1 km S	PW [a]-1	512 ± 65	191 ±11	9.0 ± 0.2	3.0 ±1	93 ±3.1	11.0 ±1.4	819	0.02
	PW-2	1123 ±41	400 ±13	13.0 ±0.3	4.3 ± 2	197 ± 0.9	27.0 ± 0.3	1764	0.01
5 km S	DW [b]-1	175 ± 10.6	< 1	2.4 ± 0.2	< 1	32.2 ±1.1	2.5 ± 0.1	212	0.01
	DW-2	443 ± 10	< 1	5.2 ±0.4	< 1	108 ± 4.8	16.2 ± 0.5	572	0.01
	DW-3	365 ± 1.7	< 1	3.3 ± 0	< 1	36.1 ± 2.1	2.6 ± 0.1	407	0.01
20 km N	DW-4	< 1	< 1	< 1	< 1	< 1	< 1	0	-
18 km NW	RR [c]-1	236 ± 3.8	68.0 ±1.2	3.2 ±0	< 1	36.3 ± 0.5	4.0 ± 0	348	0.01
	RR-2	261 ± 12.8	73.0 ± 0.7	3.0 ± 0.2	< 1	45.4 ± 0.9	5.3 ± 0.5	388	0.01
20 km NW	RR-3	807 ± 40.8	126 ± 3.1	6.6 ± 0.1	< 1	121 ± 2	15.0 ± 0.7	1076	0.01
	RR-4	155 ± 13	75.2 ± 0.9	3.0 ± 0.2	< 1	54.0 ± 0.8	8.0 ± 0.2	295	0.02

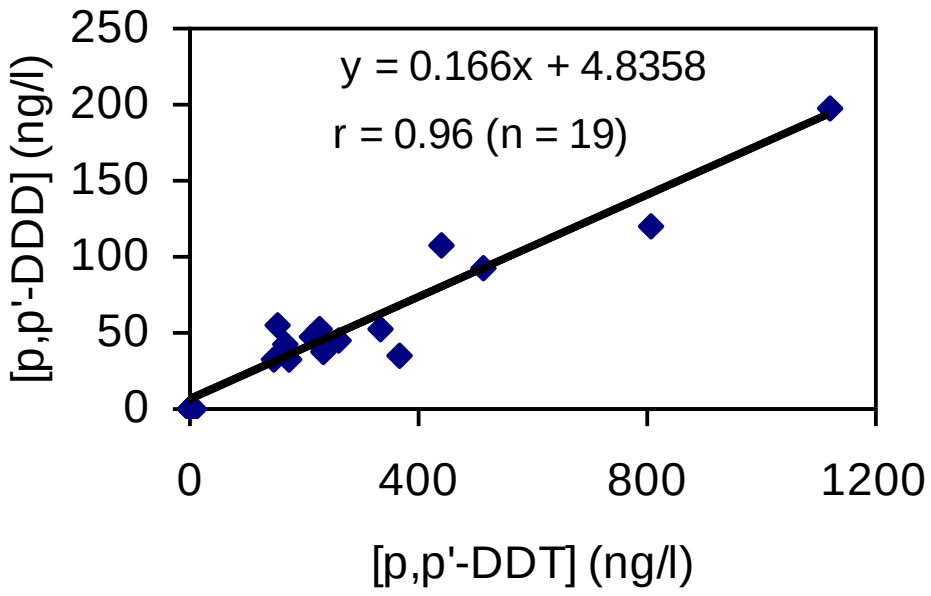
4 km N	RC [d]-1	168 ± 25	22.0 ± 0.5	4.3 ± 2±	< 1	43.0 ± 0.8	6.0 ± 0.5	243	0.03
	RC-2	215.0 ± 0.8	52.2 ± 1.3	3.0 ± 0.1	< 1	48.4 ± 0.4	6.0 ± 0	324.6	0.01
6 km N	RC-3	332 ± 13	< 1	3.3 ± 0.1	< 1	53.2 ± 2.7	3.0 ± 3.7	392	0.01
	RC-4	227 ± 0.5	< 1	3.2 ± 0.1	< 1	53.0 ± 0.1	6.4 ± 0.3	290	0.01
7 km N	RC-5	147 ± 2.7	< 1	2.3 ± 0.1	< 1	31.5 ± 1.1	5.3 ± 0.2	186	0.02
22 km N	RC-6	5.0 ± 0.9	< 1	< 1	< 1	< 1	< 1	5.0	≈ 0.20
24 km N	RC-7	2.1 ± 0.7	< 1	< 1	< 1	< 1	< 1	2.1	≈ 0.47
	RC-8	< 1	< 1	< 1	< 1	< 1	< 1	0	-
25 km N	RC-9	4.0 ±1	< 1	< 1	< 1	< 1	< 1	4	≈ 0.25

[a] Pond water [b] Dug well (Drinking) water [c] River Ruvu water [d] River Chombe water

The concentrations of DDD were higher than for DDE in all samples. This can be explained by the fact that, DDD is both a metabolite of DDT under anaerobic degradation, and is pesticidal enough to be used as a pesticide on its own, in which case it has been sold under the name rothane and has the ISO approved name of TDE. On the other hand, the only source of DDE is through aerobic degradation of DDT, in which DDE is the main product [12]. These findings support the contention that the point source contained DDD as a pesticide product, which was one of the key findings at the point source, where DDD was also found at such high concentrations that it could not be explained by the degradation of DDT alone [4,5]. There are very strong positive correlations between the concentrations of most of the detected compounds in water. For example, the concentrations of *p,p*'-DDT, *p,p*'-DDE and *p,p*'-DDD correlate very strongly with each other (Fig.2), which suggests that they have a common source.



(a)



(b)

Figure 2: Correlations in the concentrations of (a) *p,p'*-DDT and *p,p'*-DDE (b) *p,p'*-DDT and *p,p'*-DDD in water

The DDE/DDT ratios can be used to establish whether the contaminating input occurred recently or in the past, and whether degradation was significant or not. A high ratio indicates old inputs of DDT, which have now been largely converted to DDE or significant degradation, while a low ratio indicates recent inputs of DDT or insignificant degradation [13; 14]. The DDE/DDT ratios were low (0.01 to 0.47) in all of the water samples (Table 1), indicating inputs of significantly non-degraded DDT from the point source. Low DDE/DDT ratios were also found in soil at the point source [4].

The concentrations of total DDT in pond water (PW-1 and PW-2) and River Ruvu water (RR-3) were about 2–5 times greater than the Australian and New Zealand guidelines for aquatic ecosystems for fish and crustaceans. Acute toxicity (LC_{50}) for DDT to most sensitive freshwater fish occurs at 450 ng/l and freshwater crustaceans at 360 ng/l. The concentrations of total DDT in water from two sites, i.e. River Ruvu (RR-2) and River Chombe (RC-3) were slightly greater than the LC_{50} for the most sensitive crustaceans [15]. The concentrations of *p,p*'-DDT in all the three drinking water samples collected at 5 km S, were about 2 to 4.4 times greater than the European Union (EU) maximum limit (100 ng/l) [16], indicating potential risk and concern to public health. The concentration of *p,p*'-DDT in the drinking water sample collected from 20 km N was below 2 ng/l, therefore below this limit. The concentration of *p,p*'-DDD in one of the three drinking water samples at 5 km S was about 1.1 times higher than the EU limit (100 ng/l) [16]. The concentrations of *o,p'*-DDT, and *p,p'*-DDE, were below this limit. The concentrations of total DDT in drinking water were lower than the Tanzanian limit (1000 ng/l) [17] and the WHO limit (2000 ng/l) [18]. One drinking water sample at 5 km S had a concentration of total DDT slightly greater than the EU limit (500 ng/l) [16].

DDT, DDE and DDD have been linked to many deleterious chronic effects in human and animals including endocrine disruption, changes of liver enzymes, increased occurrence of liver tumours, reproductive defects, breast cancer and egg-shell thinning [19; 20].

Hexachlorocyclohexanes

The only HCHs detected in some water samples were α-HCH (26%), β-HCH (53%) and γ-HCH (32%). In the rivers, the highest concentrations (± SD) were 18 (± 0.4) ng/l for α-

HCH (25 km N), 19 (± 3.2) ng/l for β-HCH (22 km N), and 1139 (± 276) ng/l for γ-HCH (24 km N). In pond water, the highest concentrations (± SD) were 2.3 ng/l for α-HCH, 11 (± 0.5) for β-HCH, and 10 (± 0.3) ng/l for γ-HCH (1 km S). In drinking water the highest concentrations (± SD) were 10 (± 0.1) ng/l for γ-HCH (20 km N), and < 2 ng/l for α-HCH and β-HCH (Table 2). The distribution of HCHs showed a different trend from that of DDT residues suggesting an additional input of lindane from recent use in nearby areas particularly around 22 to 25 km north along River Chombe.

The ratios of α-HCH to γ-HCH (lindane) can be used to trace the amount of active ingredients and transport pathway of the HCHs. This ratio should be 4–7 for technical HCH, and nearly zero for technical lindane [21]. γ-HCH was the dominant HCH-isomer in water samples collected from 1 km S, and 20-25 km N. The low α-HCH/γ-HCH ratios (Table 2) indicate the input of the pesticide lindane from the point source at Vikuge and maybe some from recent use in nearby areas. Lindane is still allowed for use as a pesticide in Tanzania [22]. These findings are generally similar to the previous findings at the point source where the proportions of HCHs were found to represent the presence of HCH mixtures consisting of lindane [with α-HCH/γ-HCH ratios of 0.7–3; indicated in about 63% of soil samples] and technical HCH [with α-HCH/γ-HCH ratios of > 4; indicated in about 37% of soil samples and most of the water samples] [4]. Water samples collected from 1 km S, 4 km N, 6 km N, 7 km N and 18 km NW show a predominance of β-HCH and little or no γ-HCH and α-HCH (Table 2), indicating that at least part of the source of contamination consisted of remains of a crude HCH-mixture, and are consistent with the findings at the source [4]. Another possible explanation can be due to the fact that, among the HCH isomers, β-HCH has the longest half-life in the environment [23].

Table 2: Mean concentrations of HCHs in water (ng/l ± SD, n = 2) analyzed by GC-MS

Location	Source	α-HCH	β-HCH	γ-HCH	Total HCH	α-/γ-HCH
1 km S	PW [a]-1	2.3 ± 0.05	11 ± 0.5	10 ± 0.3	23	0.24
	PW-2	< 2	5 ± 0.4	< 2	5	-
5 km S	DW [b]-1	< 2	< 2	< 2	-	-
	DW-2	< 2	< 2	< 2	-	-
	DW-3	< 2	< 2	< 2	-	-
20 km N	DW-4	< 2	2.2 ± 0.1	10 ± 0.1	12	< 0.2
18 km NW	RR [c]-1	< 2	< 2	< 2	-	-
	RR-2	< 2	4 ± 0.2	< 2	4	-
20 km NW	RR-3	< 2	< 2	< 2	-	-
	RR-4	< 2	< 2	< 2	-	-
4 km N	RC [d]-1	< 2	< 2	< 2	-	-
	RC-2	< 2	4 ± 0.2	< 2	4	-
6 km N	RC-3	< 2	4 ± 0.1	< 2	4	-
	RC-4	< 2	6 ± 0.2	< 2	6	-
7 km N	RC-5	< 2	4 ± 0.1	< 2	4	-
22 km N	RC-6	15.7 ± 0.7	19 ± 3.2	1023 ± 7	1058	0.02
24 km N	RC-7	17.4 ± 3.6	11 ± 0.7	1139 ± 276	1167	0.02
	RC-8	4.1 ± 0.5	< 2	206 ± 6	210	0.02
25 km N	RC-9	17.7 ± 0.4	< 2	1129 ± 19	1147	0.02

[a] Pond water [b] Dug well (Drinking) water [c] River Ruvu water [d] River Chombe water

There is a very strong positive correlation between the concentrations of α-HCH and γ-HCH (r = 0.995, n = 19, p < 0.01), which suggests that they have common pollution sources. No correlation was found between total DDT and total HCH, suggesting probable different environmental fate processes.

The concentrations of lindane (99% γ-HCH) in River Chombe water (RC-6, RC-7 and RC-9, Table 2) were either about the same values or

slightly greater than the Australian and New Zealand guidelines for aquatic ecosystems. Acute toxicity occurs at LC_{50} of 1100 ng/l for most sensitive fish such as *Clarius batrachus* [16]. The highest concentration of lindane in drinking water (10 ng/l) was far below the Tanzanian limit (3000 ng/l) [17], and the WHO limit (2000 ng/l) [18]. HCH isomers disrupt the immune function by affecting white blood cells, kidneys, calcium metabolism, and are carcinogenic to some animals [24].

Pentachloroanisole, aldrin and dieldrin

Pentachloroanisole, aldrin, and dieldrin were detected in 100%, 10.5% and 21.1% of the water samples, respectively. In the rivers, the highest concentrations (± SD) were 21.4 (± 1.2) ng/l for pentachloroanisole (4 km N), 8.0 (± 0.7) ng/l for aldrin (25 km N), and 6.0 (± 0.6) ng/l for dieldrin (25 km N). In pond water, the highest concentrations (± SD) were 29.2 (± 0.1) ng/l for pentachloroanisole, and 5.2 (± 0.6) ng/l for aldrin. In drinking water the highest concentration (± SD) for pentachloroanisole was 10.5 (± 0.4) ng/l (Table 3).

Table 3: Mean concentrations of pentachloroanisole, aldrin and dieldrin in water (ng/l ± SD, n = 2) analyzed by GC-MS

Location	Source	Pentachloroanisole	aldrin	dieldrin
1 km S	PW [a]-1	29.2 ± 0.1	5.2 ± 0.6	< 2
	PW-2	21.4 ± 0.3	< 2	< 2
5 km S	DW [b]-1	10.0 ± 0.2	< 2	< 2
	DW-2	10.5 ± 0.4	< 2	< 2
	DW-3	7.5 ± 0.4	< 2	< 2
20 km N	DW-4	1.3 ± 0.1	< 2	< 2
18 km NW	RR [c]-1	10.9 ± 0.6	< 2	< 2
	RR-2	10.2 ± 0.2	< 2	< 2
20 km NW	RR-3	8.4 ± 0.3	< 2	< 2
	RR-4	3.7 ± 0.3	< 2	< 2
4 km N	RC [d]-1	21.4 ± 1.2	< 2	< 2
	RC-2	13.9 ± 0.3	< 2	< 2
6 km N	RC-3	13.8 ± 0.1	< 2	< 2
	RC-4	10.4 ± 0.2	< 2	< 2
7 km N	RC-5	5.2 ± 0.1	< 2	< 2
22 km N	RC-6	3.7 ± 0.2	< 2	6.0 ± 0.3
24 km N	RC-7	3.0 ± 0.4	< 2	4.4 ± 0.2
	RC-8	2.6 ± 0.6	< 2	4.0 ± 0.6
25 km N	RC-9	5.4 ± 0	8.0 ± 0.7	6 ± 0.6

[a] Pond water [b] Dug well (drinking) water [c] River Ruvu water [d] River Chombe water

Formation of pentachloroanisole in the environment may result from the degradation of pentachlorophenol or pentachloronitrobenzene [25]. Therefore, the presence of pentachloroanisole in all water samples suggests the presence of pentachlorophenol or pentachloronitrobenzene at the source, or the use of these pesticides in the nearby areas. Pentachlorophenol is used as a wood preservative (fungicide), soil fumigant for termites, herbicide for crops and preservative for glues. Pentachloronitrobenzene is a fungicide used as a seed dressing or soil treatment to control a wide range of fungi species in such crops as potatoes, cotton, rice, wheat, onions, and tomatoes [25].

The strong positive correlation between the concentrations of *p,p'*-DDE and pentachloroanisole (r = 0.79, n =19, p < 0.01) suggests that they have a common pollution source. No correlation was found between the concentrations of aldrin and dieldrin, suggesting that dieldrin was not mainly formed as a metabolite of aldrin, but may be present at the source as a pesticide.

The concentrations of aldrin and dieldrin were approaching or above the low reliability guideline figures for aquatic

ecosystems of 1 ng/l and 10 ng/l, respectively. All concentrations of aldrin and dieldrin in drinking water were less than 2 ng/l, therefore were below the EU limit (30 ng/l) [16], Tanzanian limit (30 ng/l) [17], and WHO limit (30 ng/l) [18].

CONCLUSIONS

The level of contamination of surface waters by organochlorine pesticide residues has been indicated to be high. The strong positive correlations in the concentrations of most of the detected compounds and the similarities of most findings with the previous data at the former storage site suggest that most of the pesticide residues are coming from that point source. However, some results such as those of HCHs in some cases indicate additional inputs due to recent use in nearby areas. These findings indicate potential risks and concerns to public health and the environment at large. There is an urgent need for decontamination at the point source.

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