Distribution of Pesticide Residues in Soil and Sediments from Areas of Coast Region Near a Heavily Contaminated Site in Tanzania

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Soil and sediment samples collected from 0.1 to 25 km away from a heavily contaminated site at Vikuge farm in Coast region were extracted, cleaned by GPC and analyzed using GC-ECD and GC-MS. Ten 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 and γ-HCH were detected in the samples. In general, contaminants during this round of sampling were widespread. The compounds *o,p'*- and *p,p'*-DDT, DDD and DDE were detected in 64.3% - 100% of the samples. Pentachloroanisole was detected in 95.5% of the soil and 50% of the sediment samples, while for the HCH isomers, the highest frequency was for β-HCH (57.1%) in sediments. The concentrations of total DDT were up to 534 ng/g dry weight (dw) in soil and 1945 ng/g dw in sediments. The highest concentrations for total HCH were 3.8 ng/g dw in soil and 24.6 ng/g dw in sediments. The very strong positive correlations in the concentrations of the detected compounds suggest a common source. The low DDE/DDT ratios (0.01 - 0.83) in all but one sample indicate input of significantly non-degraded DDT from the source. The high DDE/DDT ratio (1.35) in one soil sample indicates significant degradation. The low α-HCH/γ-HCH ratios in the samples indicate inputs of lindane. There is an urgent need for remedial actions to solve the problem at the source.

INTRODUCTION

The UN Food and Agriculture Organization (FAO) have stated that the amount of toxic waste of obsolete pesticides in Africa is higher than previously estimated [1]. Every African country has stockpiles of obsolete pesticides and associated waste such as heavily contaminated soils and millions of containers [2]. According to a recent FAO estimate, the toxic waste amount in Africa is around 120,000 tonnes, with more than 500,000 tonnes worldwide. About 30% of wastes are persistent organic pollutants (POPs) and less than 5% of the estimated stockpiles have been disposed of [3]. These pesticides are a serious threat to health for both rural and urban populations, especially for the poorest ones; and the environment [3]. In many developing countries, management of pesticides is often inadequate due to lack of resources. Many of these countries suffer from weak import controls, poor storage and stock management, as well as lack of training in appropriate pesticide use [3].

In Tanzania, there are more than 1100 tonnes of obsolete pesticides, 20% of which are organochlorines [2]. As no adequate hazardous waste destruction facilities exist in Tanzania, wastes such as heavily contaminated soils in some cases have so far remained point sources of environmental contamination [4].

At Vikuge State Farm in Kibaha district, a shed that was used for temporary storage of about 170 tonnes of pesticides donated by Greece to the Tanzanian Ministry of Agriculture in 1986 collapsed in 1990 [5]. There is no proper documentation of information about the types of pesticides that were in the donated consignment. However, it is well known that the consignment was in poor condition, in damaged packages and in some, the labels were missing or written in Greek [6]. The pesticides remained exposed to sunlight, wind and rain until 1996 when a new store was built by the government with aid from SIDA and the pesticides were collected, repacked and kept in that store. The soil at the former storage site however, was found to be heavily contaminated in 2001 [5,6] and this prompted us to design a study with the aim of establishing the distribution of pesticide residues from this source.

In this study, we investigated the extent of distribution of pesticide residues in soils and sediments up to 25 km from the source.

EXPERIMENTAL

Sampling

Soil samples were collected in September 2002 from sites at 0.3 to 5 km south, 0.1 to 24 km north and 18 to 20 km northwest, of the heavily contaminated site at Vikuge farm (6^0 47'S, $38^0$52'E) in Coast region, Tanzania (Fig. 1). The samples were collected by taking the surface soil (up to 5 cm deep) using spoons and spatulas, which were thoroughly cleaned with clean tissue papers after every sampling. Surface sediment samples were collected from a pond (1 km south), Chombe river (3 – 25 km north), Ruvu river (18 and 20 km northwest) and a dug well (5 km south) (Fig.1) up to a depth of 5 cm, using a hoe, spoons and spatulas, which were thoroughly cleaned prior to use. At each sampling point two samples of soil or sediments were collected. Each sample was wrapped in an aluminium foil and placed in a plastic bag. The samples were kept in a freezer at –18°C until extraction.

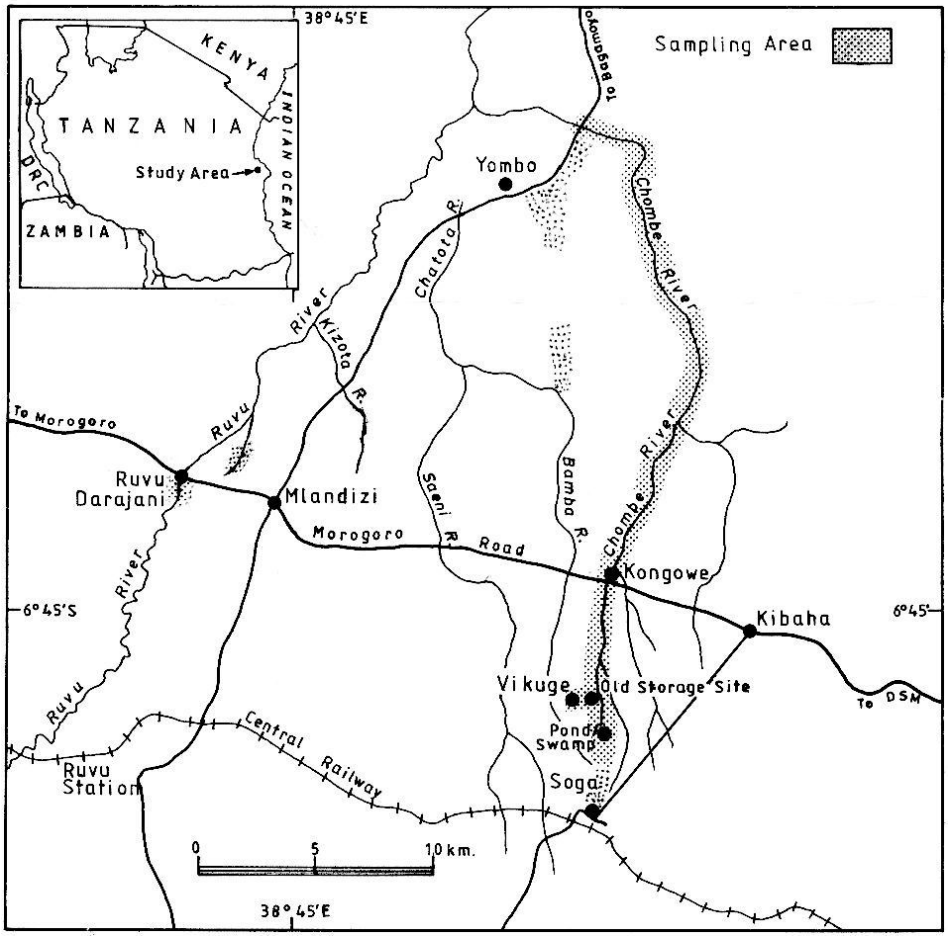


Figure 1: Map showing the study area

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 standard pesticides were prepared by dissolving 10-50 mg of each compound in cyclohexane and were stored in glass-stoppered flasks at –18°C. Mixed compounds, calibration and measuring standards in cyclohexane were prepared from the stock solutions. Chromatography grade cyclohexane, acetone and ethyl acetate were purchased from Ultrafine Ltd., London. Ammonium chloride, sodium chloride and sodium sulphate were of analytical grade and were obtained from Rochelle Chemicals & Lab

Equipment, South Africa. 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

Two sub-samples of soil (20 g each) were prepared for each sample, one for extraction and the other for determination of dry weight. The sub-sample for extraction of pesticides was quantitatively transferred into a 250-ml stoppered flask, in which, 0.2 M ammonium chloride solution (14 ml) was added and the mixture was swirled for two minutes. The flask and its contents were left to stand for 15 minutes before cyclohexane: acetone (1:1, 100 ml) was added. The flask was tightly stoppered and vigorously shaken for one minute, and then less vigorously after every ten minutes for one hour and was let to stand overnight. Subsequently, the contents were intermittently shaken for two hours and were left to settle.

Distilled water was cautiously added until the organic layer rose to the neck of the flask. The organic phase was then Pasteur pipetted into an E-flask that contained oven pre-dried anhydrous sodium sulphate (ca. 20 g). The flask was swirled and left to stand for 15 minutes, after which the contents were decanted through a plug of glass wool into an evaporation flask. The remaining sodium sulphate was rinsed with acetone (30 ml) and again decanted through the same glass wool plug. The resulting organic solution was concentrated and solvent changed to cyclohexane/ethylacetate (1:1) to obtain a volume of 1 ml [7].

Two sub-samples of sediments (10 g each) were obtained for each sample, one for extraction and another for determination of dry weight. The sub-sample for extraction was ground with Na_2SO_4 (30 g) in a mortar. The powder was extracted in a flask by shaking for about 5 minutes successively with 50, 20, 20, 20 ml cyclohexane/acetone, then filtered into a flask and poured into a separating funnel in which 10% saturated NaCl solution (200 ml) was added and shaken. The phases were let to separate. The aqueous (lower) phase was drawn into a flask. The organic phase was put in a teflon-stoppered bottle. The aqueous phase was extracted with ethyl acetate/cyclohexane (15:85 v/v, 50 ml). The organic phases were combined in an E-flask containing Na_2SO_4 (15-20 g). The E-flask was shaken and left for 15 minutes and shaken again checking that the Na_2SO_4 flowed freely, if not, more Na_2SO_4 was added and shaking repeated. The extracts were decanted through a plug of glass wool into an evaporation flask. The Na_2SO_4 was rinsed with ethyl acetate/cyclohexane (30 ml) and decanted through the same glass wool plug. The extract was concentrated to 1 ml ready for GPC clean up [7].

Clean up

Gel Permeation Chromatography (GPC) clean up was performed using 50 cm x 1 cm i.d. chromatographic tube, with two adaptors, six-way valve with 1 ml sample injector loop and teflon tubing (Pharmacia no SR 10/50, Uppsala, Sweden), elution with cyclohexane/ethylacetate (1:1 v/v). The GPC was calibrated using *p,p'*-DDD and *p,p'*-DDE [5]. Pesticides were eluted in the range 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 was evaporated and changed to 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 in 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, 30 °C/min to 180 °C, 4 °C/min to 260 °C 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, Neuherberg, Munich in 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 for 1 min, 12

°C/min to 140 °C, 5 °C/min to 210 °C for 1 min, 12 °C/min to 280 °C held for 3 min. The carrier gas (helium) was in constant flow mode at column head pressure of 50 kPa. Splitless injection of a 1 µl volume was carried out at 250 °C. The mass spectrometer was operated in an electron ionization mode, quadrupole-MS, with interface temperature of 280 °C, ion source 220 °C, selected ion monitoring mode using two different m/z for each analyte, and the scan mode for all samples was m/z 50 – 500. 10 µl of internal standard solution (a 10 ng/µl mixture of ^{13}C-labelled HCB, *p,p'*-DDT and *p,p'*-DDE, Dr. Ehrenstorfer, Germany) were added to each of the sample extracts and to the mixtures of calibration standards. The GC/MS was calibrated by means of five 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 external 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 [8] using two different *m/z* for each analyte.

Analytical quality assurance

A 100 ml aliquot of each cyclohexane, ethyl acetate and acetone was concentrated to 2 ml and used to check the contamination from the reagents used. Four matrix blanks were also obtained from 60 km away, east of the source. No significant peaks appeared in the chromatograms of the blanks. Recoveries were estimated by spiking the leaves (60 km E) with 13 organochlorine pesticide standards at concentrations ranging from 0.01 – 1 µg/ml of each analyte. The average recoveries ± SD in soil (n = 2) for fenitrothion, pentachlorobenzene, aldrin, dieldrin, α-HCH, β-HCH, γ-HCH, δ-HCH, *p,p'*-DDT, *o,p'*-DDT, *p,p'*-DDE, *p,p'*-DDD, *cis*-chlordane and chloropyriphos ranged from 71.2% ± 1.7 to 88.2% ± 3.4, while in sediments (n =2) ranged from 77% ± 2 to 93.3% ± 2.6. The results were not corrected for recoveries since they were within the normal acceptable range of 70 – 110% [9]. The detection limits in soil were 0.2 ng/g for DDT, DDE, DDD, pentachlorobenzene, pentachloroanisole, aldrin, dieldrin and HCHs (α-, β-, γ-, δ-, and ε-HCH); and 1.0 ng/g for heptachlor, *cis*-heptachlor epoxide, *trans*-heptachlor epoxide, oxy-chlordane, and *cis*-chlordane. The detection limits in sediment samples were 0.2 ng/g for DDT, DDD and DDE; 0.5 ng/g for pentachlorobenzene, pentachloroanisole and α-HCH; and 1.0 ng/g for β-HCH, γ-HCH, δ-HCH, ε-HCH, aldrin, dieldrin, heptachlor, *cis*-heptachlor epoxide, *trans*-heptachlor epoxide, oxy-chlordane, and *cis*-chlordane.

RESULTS AND DISCUSSION

Pesticide residues in soil

DDTs (*p,p*'-DDT and *o,p*'-DDT) and their metabolites (*p,p*'-DDD, *o,p*'-DDD, *p,p*'-DDE, and *o,p*'-DDE) were detected in some soil samples. Their concentrations are summarized in Table 1. The highest concentrations (± SD) ranged from 0.7 (± 0.2) ng/g dw for *o,p*'-DDE to 403.7 (± 12.9) ng/g dw for *p,p*'-DDT (all found at 0.1 km N). The highest concentration of total DDT at 0.1 km N was 534 ng/g dw. The mean concentrations of DDT residues in soil samples

Table 1: Average concentrations of DDT and metabolites in soil (ng/g dw ± SD, *n* = 2)

Site	*p,p'*-DDT	*o,p'*-DDT	*p,p'*-DDE	*o,p'*-DDE	*p,p'*-DDD	*o,p'*-DDD	∑DDT	DDE/DDT
0.1 km N, A	403.7 ± 12.9	40.0 ± 2.3	54.2 ± 0.9	0.7 ± 0.2	33.3 ± 0.7	2.0 ± 0.04	533.9	0.13
B	245.7 ± 15.4	20.0 ± 0.7	38.3 ± 2.5	0.6 ± 0.05	24.3 ± 0.5	2.0 ± 0.07	330.9	0.16
1 km N, A	11.2 ± 0.3	Bdl	1.4 ± 0.07	Bdl	2.9 ± 0.2	0.2 ± 0.01	15.7	0.12
B	3.7 ± 0.1	Bdl	0.7 ± 0.01	Bdl	1.4 ± 0.02	Bdl	5.8	0.18
2 km N	1.6 ± 0.2	Bdl	0.3 ± 0.01	Bdl	0.4 ± 0.02	Bdl	2.3	0.16
3 km N	0.8 ± 0.02	Bdl	0.2 ± 0.06	Bdl	0.3 ± 0.08	Bdl	1.3	0.25
4 km N	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	-	-
6 km N	2.7 ± 0.4	Bdl	0.2 ± 0.02	Bdl	0.5 ± 0.06	Bdl	3.4	0.07
7 km N, A	0.4 ± 0.03	Bdl	Bdl	Bdl	0.3 ± 0.1	Bdl	0.7	< 0.57
B	0.2 ± 0.1	Bdl	Bdl	Bdl	Bdl	Bdl	0.2	< 0.83
15 km N	1.9 ± 0.04	Bdl	0.2 ±0.01	Bdl	0.4 ± 0.03	Bdl	2.5	0.12
20 km N, A	1.6 ± 0.3	Bdl	0.2 ±0.01	Bdl	0.4 ±0.04	Bdl	2.2	0.13
B	4.6 ± 0.4	Bdl	0.4 ± 0.01	Bdl	1.0 ± 0.01	0.3 ± 0.01	6.3	0.09
24 km N, A	2.7 ± 0.03	Bdl	Bdl	Bdl	0.6 ± 0.04	Bdl	3.3	< 0.07
B	0.2 ± 0.01	Bdl	0.3 ± 0.01	Bdl	0.7 ± 0.01	Bdl	1.2	1.35
0.3 km S, A	1.2 ± 0.2	Bdl	0.3 ± 0.06	Bdl	0.6 ± 0.06	Bdl	2.1	0.24
B	2.6 ± 0.3	Bdl	0.3 ± 0.07	Bdl	1.2 ± 0.1	0.2 ± 0.07	4.3	0.13
1 km S, A	4.0 ± 0.6	2.0 ± 0	2.2 ± 0	Bdl	1.7 ± 0.02	0.3 ± 0	10.2	0.56
B	3.1 ± 4.3	Bdl	2.0 ± 2.8	Bdl	2.6 ± 3.6	0.5 ± 0.4	8.2	0.64
5 km S	15.1 ± 1.4	2.0 ± 0.01	2.8 ± 0.07	Bdl	2.0 ± 0.2	Bdl	21.9	0.19
18 km NW	1.2 ± 0.2	Bdl	0.2 ± 0.01	Bdl	0.4 ± 0.1	Bdl	1.8	0.17
20 km NW	1.0 ± 0.05	Bdl	Bdl	Bdl	Bdl	Bdl	1.0	< 0.21

Bdl = Below detection limit

(ng/g dw ± SD) were in the order *p,p'*-DDT (32 ± 98) > *p,p'*-DDE (5 ± 14) > *p,p'*-DDD (3.4 ± 8.4) = *o,p'*-DDT (2.9 ± 9) > *o,p'*-DDD (0.2 ± 0.6) > *o,p'*-DDE (0.1 ± 0.2). The compounds *p,p'*-DDT, *p,p'*-DDD and *p,p'*-DDE were detected in 95.5%, 86.4% and 77.3% of the soil samples, respectively. The other compounds *o,p'*-DDD, *o,p'*-DDT and *o,p'*-DDE were detected in 31.8%, 18.2% and 9.1% of the soil samples, respectively.

Pentachloroanisole, α-HCH, β-HCH and γ-HCH were detected in some soil samples (Table 2). The highest concentrations (± SD) were 1.8 (± 0.01) ng/g for pentachloroanisole, 0.4 (± 0.01) ng/g for α-HCH, 2.7 (± 0.3) ng/g for β-HCH and 0.7 (± 0.03) ng/g for γ-HCH (all found at 0.1 km N). The compounds α-HCH, β-HCH and γ-HCH were detected in 13.6%, 22.7% and 9.1% of the soil samples, respectively. Pentachloroanisole was found in 21 out of the 22 soil samples (95.5%).

Table 2: Average concentrations of pentachloroanisole and HCHs in soil (ng/g dw ± SD, n = 2)

Site	Pentachloroanisole	α-HCH	β-HCH	γ-HCH	α-/γ-HCH
0.1 km N A	1.4 ± 2.0	0.4 ± 0.01	2.7 ± 0.3	0.7 ± 0.03	0.6
B	1.8 ± 0.01	0.3 ± 0.02	1 ± 0.03	0.5 ± 0.03	0.6
1 km N A	0.2 ± 0.01	Bdl	Bdl	Bdl	-
B	0.7 ± 0.01	Bdl	Bdl	Bdl	-
2 km N	0.2 ± 0.01	Bdl	1 ± 0.01	Bdl	-
3 km N	0.2 ± 0.01	Bdl	0.9 ±0.02	Bdl	-
4 km N	0.2 ± 0	Bdl	Bdl	Bdl	-
6 km N	0.5 ± 0.01	0.3 ± 0.01	1 ± 0.05	Bdl	> 1.5
7 km N A	0.3 ± 0.03	Bdl	Bdl	Bdl	-
B	0.5 ± 0.03	Bdl	Bdl	Bdl	-
15 km N	0.4 ± 0	Bdl	Bdl	Bdl	-
20 km N A	0.4 ± 0.04	Bdl	Bdl	Bdl	-
B	0.3 ± 0.01	Bdl	Bdl	Bdl	-
24 km N A	0.3 ± 0.03	Bdl	Bdl	Bdl	-
B	0.4 ± 0	Bdl	Bdl	Bdl	-
0.3 km S A	Bdl	Bdl	Bdl	Bdl	-
B	0.2 ± 0.01	Bdl	Bdl	Bdl	-
1 km S A	0.7 ± 0	Bdl	Bdl	Bdl	-
B	0.3 ± 0.5	Bdl	Bdl	Bdl	-
5 km S	0.2 ± 0.03	Bdl	Bdl	Bdl	-
18 km NW	0.3 ± 0.04	Bdl	Bdl	Bdl	-
20 km NW	1.0 ± 0.4	Bdl	Bdl	Bdl	-

Pesticide residues in sediments

The DDT residues detected in sediments were *p,p*'-DDT, *o,p*'-DDT, *p,p*'-DDD, *o,p*'-DDD, *p,p*'-DDE and *o,p*'-DDE. The highest concentrations (± SD) on dry weight basis ranged from 5.3 (± 0.2) ng/g for *o,p*'-DDE to 1726.9 (± 80.8) ng/g for *p,p*'-DDT, and all were found at 18 km NW except for *o,p*'-DDT (31 ± 0.5 ng/g) found at 5 km S. The concentrations of total DDT ranged from 0.5 to 1945 ng/g dw (Table 3). The mean concentrations of DDT residues in sediments samples (ng/g dw ± SD) were in the order *p,p'*-DDT (240.3 ± 449.4) > *p,p'*-DDD (22 ± 36.9) > *o,p'*-DDT (15 ± 13.1) > *p,p'*-DDE (4.3 ± 5.5) > *o,p'*-DDD (3 ± 5) > *o,p'*-DDE (1 ± 1.3).

Pentachloroanisole, α-HCH, β-HCH and γ-HCH were also found in some sediment samples. Their concentrations are presented in Table 4. β-HCH was detected in 57.1% of the samples; pentachloroanisole was detected in 50% of the samples, whereas α-HCH and γ-HCH

were detected in 14.3% of the samples. The highest concentrations for pentachloroanisole, α-HCH, β-HCH and γ-HCH in sediments were found at 22 km N. The highest concentrations were up to 1.6 ng/g dw for pentachloroanisole and 24.6 ng/g dw for total HCH.

Table 3: Average concentrations of pentachloroanisole and HCHs in sediments (ng/g dw ± SD, n = 2)

Site	Source	Pentachloroanisole	α-HCH	β-HCH	γ-HCH	α-/γ-HCH
3 km N	RC[a]-1	Bdl	Bdl	6.5 ± 0.4	Bdl	-
4 km N	RC-2	Bdl	Bdl	2.9 ± 0.03	Bdl	-
6 km N	RC-3	Bdl	Bdl	1.8 ± 0.01	Bdl	-
7 km N	RC-4	Bdl	Bdl	5.6 ± 0.4	Bdl	-
22 km N	RC-5	1.6 ± 0.04	0.7 ± 0.06	9.8 ± 0.9	14.1 ± 1	0.05
24 km N	RC-6	1.0 ± 0.07	Bdl	Bdl	Bdl	-
	RC-7	0.9 ± 0.06	Bdl	Bdl	Bdl	-
	RC-8	1.1 ± 0.1	0.6 ± 0.02	4.6 ± 0.3	1.3 ± 0.06	0.50
25 km N	RC-9	1.4 ± 0.04	Bdl	2.7 ± 0.1	Bdl	-
1 km S	PD[b]-1	Bdl	Bdl	Bdl	Bdl	-
	PD-2	Bdl	Bdl	7.7 ± 0.1	Bdl	-
5 km S	DW[c]	Bdl	Bdl	Bdl	Bdl	-
18 km NW	RR[d]-1	0.7 ± 0.2	Bdl	Bdl	Bdl	-
20 km NW	RR-2	1.2 ± 0.03	Bdl	Bdl	Bdl	-

[a]River Chombe [b]Pond [c]Dug well [d]River Ruvu

DISCUSSION

The proportions of DDT, DDE and DDD indicated contamination by technical DDT, which primarily contains 65 – 80% *p,p'*-DDT, and 15 – 21% *o,p'*-DDT [10]. The DDE/DDT ratios were low (0.07 - 0.83) in 91% of the soil samples (Table 1) and all sediment samples (0.01 – 0.62) (Table 3), indicating inputs of significantly non-degraded DDT [11] from the point source. These observations are similar to the previous findings around the point source [3, 4]. Only one sample at 24 km N had a high DDE/DDT ratio (1.35) (Table 1), indicating either old input of DDT or significant degradation at that point. The higher concentrations of DDD than those of DDE can be due to the fact that apart from being a degradation product of DDT by anaerobic conversion, DDD is a pesticide on its own, which has been sold under the name rothane and has the ISO approved name of TDE [12].

There are very strong positive correlations in the concentrations of *p,p'*-DDT, *p,p'*-DDE and *p,p'*-DDD in soil samples (r = 0.994 - 0.997, n = 22, $p < 0.01$) and in sediments (r = 0.97, n =14, $p < 0.05$), indicating that they have a common source. The low α-HCH/γ-HCH ratios in some soil and sediment samples indicate the input of lindane [13]. An increase in the concentration of α-HCH relative to γ-HCH in soil at 6 km might be attributed to photochemical or bacterial transformation of γ-HCH into α-HCH [14]. The predominance of the β-HCH in some soil samples and most sediment samples can be explained by the fact that it is the most resistant to biodegradation of the HCH isomers [15, 16].

Table 4: Average concentrations of DDT and metabolites in sediments (ng/g dw, ± SD, n = 2)

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
3 km N	RC[a]-1	209.5 ± 8.8	29.9 ± 0.5	4.2 ± 0	Bdl	12.2 ± 0.03	1.2 ± 0.1	257.0	0.02
4 km N	RC-2	216.9 ± 2.2	10.3 ± 0.3	4.8 ± 0.04	0.9 ± 0.08	19.1 ± 0.5	3.5 ± 0.06	255.5	0.02

6 km N	RC-3	185.3 ± 1.4	20.8 ± 1.6	4.5 ± 0.01	1.0 ± 0.2	18.8 ± 0.3	4.5 ± 0.03	234.9	0.02
7 km N	RC-4	55.8 ± 0.8	8.6 ± 0.2	2.7 ± 0.08	0.5 ± 0.03	7.4 ± 5.2	3.0 ± 0.04	78.0	0.05
22 km N	RC-5	2.8 ± 1.6	Bdl	0.2 ± 0.02	0.3 ± 0	0.5 ± 0.1	0.3 ± 0.1	4.1	0.08
24 km N	RC-6	0.3 ± 0.04	Bdl	Bdl	0.2 ± 0.01	Bdl	Bdl	0.5	0.62
	RC-7	1.5 ± 1.8	Bdl	Bdl	0.6 ± 0.07	0.5 ± 0.1	Bdl	2.6	0.14
	RC-8	7.9 ± 0.09	Bdl	0.3 ± 0	0.5 ± 0.04	1.1 ± 0.02	0.3 ± 0.01	10.1	0.04
25 km N	RC-9	3.7 ± 4.6	Bdl	0.3 ± 0	0.5 ± 0.07	0.4 ± 0.4	Bdl	4.9	0.08
1 km S	PD[b]-1	114.4 ± 10.1	20.2 ± 2	5.1 ± 0.3	0.6 ±0.04	18.2 ± 0.7	3.1 ± 0.01	161.6	0.04
	PD-2	187.2 ± 5	30.0 ± 0.6	5.8 ± 0.3	0.8 ± 0.1	22.1 ± 0.8	3.1 ± 0.4	249.0	0.03
5 km S	DW[c]	503.2 ± 4.5	31.0 ± 0.5	5.8 ± 0.2	1.1 ± 0.08	27.4 ± 1.1	2.4 ± 0.3	571.0	0.01
18 km NW	RR[d]-1	1726.9 ± 80.8	29.1 ± 1.6	21.4 ± 0.5	5.3 ± 0.2	143.5 ± 3.7	19.2 ± 0.03	1945.4	0.01
20 km NW	RR-2	148.1 ± 1.2	23.3 ± 0.5	4.7 ± 0.01	2.2 ± 0.05	37.1 ± 0.6	Bdl	215.4	0.03

[a]River Chombe [b]Pond [c]Dug well [d]River Ruvu

There are very strong positive correlations between the concentrations of total DDT and total HCH ($r = 0.97$, $p < 0.01$), *p,p*-DDE and pentachloroanisole ($r = 0.81$, $n = 22$, $p < 0.01$), and α-HCH and γ-HCH ($r = 0.72$, $n = 22$, $p < 0.01$) in soil, indicating that they have a common pollution source. A very strong positive correlation was found between the concentrations of α-HCH and γ-HCH in sediments ($r = 0.999$, $n = 14$, $p < 0.01$), indicating a common source. No correlation was found between the concentrations of pentachloroanisole and other compounds in sediments, suggesting different environmental fate processes.

Pentachloroanisole is a metabolite of pentachlorophenol or pentachloronitrobenzene [17, 18], therefore, the presence of this metabolite in most of the soil and sediment samples suggests the presence of pentachlorophenol or pentachloronitrobenzene at the source, or the use of these pesticides in the nearby areas.

p,p'-DDT, *p,p'*-DDD and *p,p'*-DDE were the most frequently detected compounds in soil samples (77.3% - 95.5%). The extent of contamination of sediments by DDT residues was found to be very extensive. Generally, the highest concentrations of DDT and metabolites in sediments samples were found at 18 km NW, suggesting significant accumulation at that site. All the sediments samples (100%) contained *p,p'*-DDT; 92.9% of the samples contained *p,p'*-DDD and *o,p'*-DDE while the compounds *p,p'*-DDE, *o,p'*-DDD and *o,p'*-DDT were detected in 85.7%, 71.4% and 64.3% of the samples, respectively.

CONCLUSIONS

In general, contaminant levels were high and widespread with noteworthy concentrations of total DDT up to 534 ng/g dw in soil at 0.1 km N and 1945 ng/g dw in sediments at 18 km NW. The compounds *p,p'*-DDT, *p,p'*-DDD, *p,p'*-DDE and pentachloroanisole were the most frequently detected pesticide residues in soil samples. Sediments samples were much more polluted by the DDTs and their major metabolites (*p,p'*- and *o,p'*-DDE and DDD) as well as pentachloroanisole and β-HCH. There was no even a single site that was found free from contamination by these pesticide residues.

Contamination of soils and sediments with these compounds appears to be related to point source contamination by pesticide residues from the heavily contaminated site at Vikuge farm in Coast region, and these are the results of weak import controls and improper storage of pesticides. The present study suggests the active transfers of these compounds from the source to various sites through runoff and volatilization followed by atmospheric deposition. The detected compounds are generally resistant to attack by abiotic or biotic agents in the environment, and thus most of these compounds persist for long periods in the environment and often exhibit half-lives of many years, for example 2-25 years for *p,p'*-DDT [19]. They have a tendency to adsorb to sediments and bioaccumulate in aquatic organisms. There is an urgent need for remedial actions to solve the problem at the source. Further work is needed to study the possibilities for remediation (e.g. phytoremediation and bioremediation) of the contaminated soil at the point source.

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