ORGANOCHLORINE PESTICIDES AND DEGRADATION PRODUCTS IN SOIL AROUND A FORMER FORMULATION PLANT IN MOROGORO MUNICIPALITY, TANZANIA

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ABSTRACT

The levels and compositions of organochlorine pesticides and degradation products in soil samples collected from a former formulation plant in Morogoro municipality, Tanzania, were determined. Extraction was performed by pressurized fluid extraction using n-hexane:acetone (75:25) mixture. Clean-up of extracts was conducted by using silica gel and alumina with 3% H_2O and the extracts were eluted with hexane and dichloromethane (1:1). Additional clean-up was performed by using C18 SPE cartridges using acetonitrile as the eluting solvent. The samples were spiked with labelled internal standards for identification and quantification. Analysis of the analytes was performed using a high resolution gas chromatograph coupled to a high resolution mass spectrometer (GC–MS). 27 organochlorine pesticides and degradation products were detected. The concentrations of total DDT and total HCH ranged 300–152000 and 2–8300 mg/kg dry weight (dw), respectively. The concentrations for other compounds were up to 1400 mg/kg dw. The results indicated old contamination by technical mixtures and lack of significant degradation. It is recommended that clean-up and proper disposal of contaminated soil should be carried out.

INTRODUCTION

Organochlorine pesticides are toxic chemicals that persist in the environment for long times, and biomagnify as they move up through the food chain. Many organochlorine pesticides (e.g. dichlorodiphenyltrichloroethane (DDT), hexachlorocyclohexanes (HCHs), aldrin, dieldrin, endrin, heptachlor and hexachlorobenzene) have been banned in many countries because of concerns on the environment and human health (UNEP 2009). However, banned organochlorine pesticides are still found in different environmental compartments due to their persistence, illegal uses, emissions from certain point sources or improper disposal (Kishimba *et al*. 2004, Marco and Kishimba 2005, 2007).

Soil is the repository of chemicals such as organochlorine pesticides. Many organochlorine pesticides have a high affinity for soil, which might be taken up by crops and by grazing animals and hence reach the human food chain. They are also washed in run-off from land into watercourse and emitted into atmosphere through volatilization, which results in water and atmospheric contamination (Bidleman and Leone 2004). Because they circulate globally via the atmosphere, rivers, oceans and other pathways, organochlorine pesticides released in one part of the world can travel to regions far from their sources of origin (Ritter *et al*. 1995, Wania and Mackay 1995).

Exposure to organochlorine pesticides can lead to serious health effects in humans and animals including certain cancers, reproductive/birth defects, damage to the nervous system, disruption of the immune system, greater susceptibility to disease and even diminished intelligence. For example, several harmful effects in wildlife

populations have been linked to DDT; these include the thinning of eggshells in birds, feminization and altered sex-ratios, and impacts on the nervous system and on behavior in animals. The lipophilic nature, hydrophobicity and low chemical and biological degradation rates of organochlorine pesticides have led to their accumulation in biological tissues and subsequent magnification of concentrations in organisms, progressing through in the food chain (Ritter *et al*. 1995, ATSDR 2002, 2005).

The objective of this study was to investigate the levels and compositions of organochlorine pesticides and degradation products in soil around a former formulation plant in Morogoro municipality, Tanzania. The area around this site was suspected to be contaminated by pesticide residues mainly due to leakage and disposal of pesticides and containers. No study had been conducted to investigate the contamination status at this site.

MATERIALS AND METHODS

The Study Area

This site is owned by the National Housing Corporation (NHC) in Morogoro. The NHC acquired that site from the former owner, a private company that operated a plant for formulation of pesticides used for fumigation and agriculture. The site is located about 2 km from the centre of Morogoro town and about 150 m from Morogoro railway station (South-East). There are distinct points or locations at this site which were deemed to be contaminated. In one location, about 10 m from the factory building, is where pesticide containers (plastic bags) had been discarded. About 25 m from this location there are two open pits in which broken concrete materials (from the old building where the pesticides were stored) had been dumped. The concrete materials were suspected to be contaminated due to leakage of pesticides. The stores were excavated in order to be used for other purposes but due to the persistent odour they were abandoned. In addition, there was a demolished store that was suspected to be contaminated with pesticides. The site is about 200 m from residential areas, 20 m from the Institute of Adult Education and 50 m from the commercial stores. The area is accessible to children and other people and cultivation activities were being carried out in the vicinity.

Sampling

Samples were collected in February 2009 from the sampling points shown in Figure 1. The samples were collected at 5 cm depth (points B and D), 10 cm depth (points A, C, F, H, J, K, L, N and O), 30 cm depth (points I and M) and 200 cm depth (points E and G).

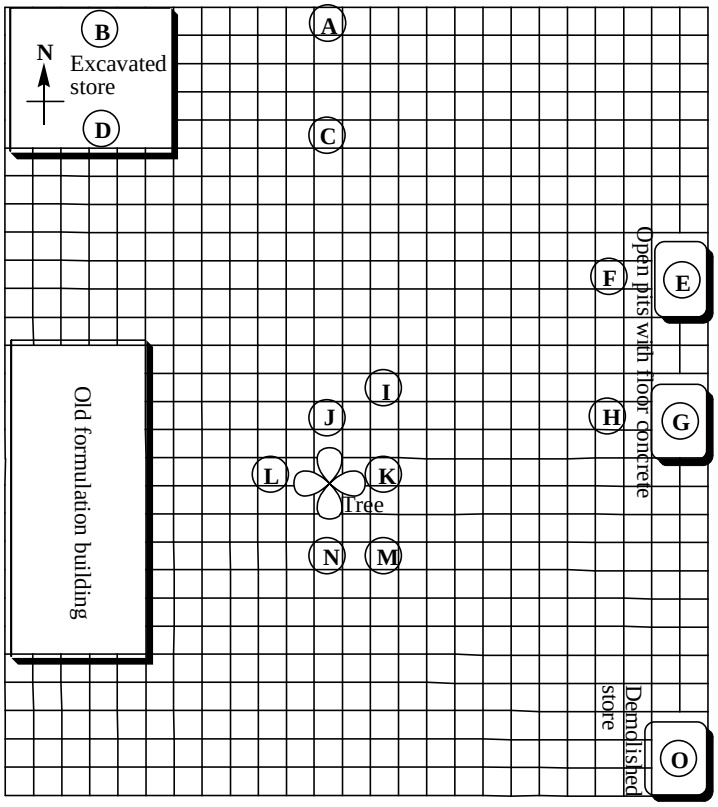

Figure 1: Map showing the sampling points at NHC-Morogoro. Each grid sq = 2 x 2 m.

The tools used for sampling of soil included clean spades, hoes, clean aluminium foil, clean buckets, measuring tapes, folding rulers, insulating boxes, solvents for cleaning, bottles for waste solvents, kitchen roll papers, polyethylene bags, waste plastic bags and stainless steel spoons. A test pit was prepared using a hoe and spade, then a slice about 5 cm thick was made along the vertical wall of the pit at the desired depth using a clean spade and the soil was thrown away (Åkerblom 1995). Another clean spade or spoon was used to take the sample. A sample was obtained by collecting at least five subsamples from different directions at the same depth within the pit. The stones, sticks, plant roots and other unwanted materials were removed by using a clean spoon. The sample was ground and mixed very thoroughly on aluminium foil. The sample was immediately wrapped in an aluminium foil and placed in a polyethylene bag then put in an insulated box. The samples were transported to the laboratory and stored in a freezer at –28 °C until extraction.

Extraction, Clean up and Gas Chromatographic Analysis

Extraction, clean up and analysis of the soil samples were conducted at the Institute of Ecological Chemistry, German Research Centre for Environmental Health in May–October 2009. The procedures by Schramm *et al*. (2008) were adopted with modifications. The soil samples were extracted by pressurized fluid extraction using an Accelerated Solvent Extractor

(ASE 200 Dionex). A cellulose filter was inserted into the inner bottom of the extraction cell, then sea sand dried at 550 °C (ca. 1 g) was added. The sample (0.5–5 g) mixed with hydromatrix for drying and dispersing was added into the cell and a filter placed on top. The samples were quantitatively extracted by an accelerated solvent extractor at a temperature of 120 °C and pressure of 120 bar and with *n*-hexane:acetone (75:25) as the extraction solvent mixture. Two static cycles of 10 min were applied for a complete extraction. Another sub-sample of each sample was dried for 24 h at 105 °C and then weighed for moisture and dry weight determination. The extracts were passed over anhydrous sodium sulfate to remove water. The extracts were concentrated using vacuum rotary evaporation to ca. 5 ml then diluted with *n*-hexane to 10 ml and some of them were diluted further by measuring 0.1 ml from that solution and diluting with *n*-hexane to 10 ml.

To remove interferences, the extracts were cleaned-up using silica gel and alumina in glass column (30 cm long with an internal diameter of 2.5 cm) packed, from bottom to top, with 10 g silica gel (grade 60), 5 g alumina with 3% H_2O and 5 g anhydrous sodium sulfate. During clean-up, 50–100 µl from the diluted sample extract were added into the column and spiked with ^{13}C–labelled and deuterated internal standards (10 µl of a mixture containing 333–1000 pg/µl of organochlorine compounds in nonane). All the internal standards for the compounds determined were ^{13}C–labelled except for 4,4'-DDD, which was a deuterated standard. The extracts were eluted with 100 ml of a mixture of hexane and dichloromethane (1:1) at a flow rate of ca. 2 drops per second (about 0.1 ml/s) and concentrated to 1 ml using a rotary evaporator, then using a very gentle stream of nitrogen to ca. 0.2 ml. The solvent was changed to acetonitrile and concentrated using nitrogen to ca. 0.2 ml. Further clean-up was performed through a C18 SPE cartridge using 1 g C18-modified silica gel and the eluting solvent used was acetonitrile (5 ml). The extracts were concentrated by blowing a very gentle stream of nitrogen to ca. 0.2 ml. The concentrated extracts were transferred into clean vials containing a recovery standard (20 µl of a 1 ng/µl solution of ^{13}C-pentachlorotoluene and ^{13}C-1,2,3,7,8,9-hexachlorodibenzo-*p*-dioxin in nonane) and extracts were concentrated with a gentle flow of nitrogen to 20 µl ready for analytical determination.

Analysis of the organochlorine pesticides and degradation products was performed using a high resolution gas chromatograph coupled to a high resolution mass spectrometer (HRGC–MS). An Agilent 6890 GC equipped with a capillary column (Rtx-Dioxin2, 40 m, 0.18 mm ID, 0.18 µm film thickness, Restek) was used. The temperature program was 60 °C (1.5 min), 25 °C/min to 140 °C (0 min), 8 °C/min to 300 °C (20 min). 0.5 µl was injected using an autosampler (A200S, CTC) in pulsed splitless mode by a cold injection system CIS 4 (Gerstel). The temperature programme for the injector was: 120 °C, 12 °C/s, 280 °C, 5 min. The carrier gas was helium in a constant flow of 1.3 ml/min. The temperature at the transferline was 300 °C. The measurement was conducted with a Finnigan MAT 95S mass spectrometer (Thermo) with a resolution of 10 000. The ionisation mode was EI at 50 eV and 260 °C and the detection was by using the selected ion monitoring (SIM) mode. The two most intense ions of the molecular ion cluster were monitored for the analytes and labelled standards. The identification and quantification criteria included confirmation of retention times, relative retention times and isotope ratios for the labelled standards and respective analytes. The mass fragment with the highest intensity of the molecular ion was used for quantification while the

other was used as a ratio mass (Schramm *et al*. 2008).

Analytical Quality Assurance and Control
Separate tools were used to collect different samples from different depths and points. Tools to be reused were thoroughly cleaned with water and soap and rinsed with dichloromethane and acetone. The labelled pesticide standards were of over 99% certified purity obtained from Dr. Ehrenstorfer (Augsburg, Germany). The standard pesticide solutions and samples were stored in glass-stoppered flasks or vials and kept deep frozen at –28 °C. All organic solvents were of picograde quality and were obtained from LGC Promochem (Wesel, Germany). After use, all glassware and tools were rinsed with a technical mixture of toluene, acetone and hexane, and washed with water and detergent in a washing machine. Thereafter, the glassware were dried in an oven overnight at programmed temperatures up to a maximum temperature of 450 °C. The silica gel was heated overnight at 550 °C to reduce background levels. Analysis of blanks, certified reference materials and recovery tests were used to check contamination and performance of the method. No significant peaks appeared in the chromatograms of the blanks. Recoveries of 13C-labelled and deuterated internal standards varied between 69% and 119% with average recoveries ranging from 77% to 99% (n = 15) and the coefficients of variation were in the range of 6–18%. The detection limit was defined as three times the average noise value measured. The limits of detection ranged from 0.0001 to 0.0006 mg/kg. The limit of quantification was three times the limit of detection and every signal below this limit was treated as not detectable.

RESULTS AND DISCUSSION

Pesticides and Degradation Products
The compounds detected in soil samples included dichlorodiphenyltrichloroethane (DDT) isomers and their major degradation products (dichlorodiphenyldichloroethylene (DDE) and dichlorodiphenyldichloroethane (DDD), hexachlorocylohexane (HCH) isomers, endosulfans, hexachlorobenzene, dieldrin, chlordane, aldrin, pentachlorobenzene, heptachlor and endrin (Table 1).

DDTs and Degradation Products
The concentrations of DDT isomers and their major degradation products are presented in Table 2. The DDT isomers and their degradation products were detected in 100% of the samples. The concentrations of total DDT in samples varied between 300 and 152000 mg/kg dw. In general, the highest concentrations of DDT isomers and degradation products varied between 620 mg/kg dw (2,4'-DDE) to 120000 mg/kg dw (4,4'-DDT). The average concentrations were in the order 4,4'-DDT > 4,4'-DDE > 2,4'-DDT > 4,4'-DDD > 2,4'-DDD > 2,4'-DDE

Table 1: Average, minimum and maximum concentrations and detection frequencies of pesticides and degradation products

Compound	**Concentration (mg/kg dw), n = 15**		**Detection Frequency (%)**
	Average	**Min –Max**	
4,4'-DDT	28000	164–120000	100
2,4'-DDT	2900	22.3–13000	100
4,4'-DDD	2120	17.3–15000	100
2,4'-DDD	450	6.3–2700	100
4,4'-DDE	3800	81–16100	100
2,4'-DDE	160	4–620	100
Total DDT	37200	300–152000	100
α-HCH	780	0.2–6900	100
β-HCH	66.2	0.32–510	100
γ-HCH	25.3	0.2–164	100
δ-HCH	69.2	0.2–643	100
ε-HCH	13.2	nd–164	33
Total HCH	1000	2–8300	100
Pentachlorobenzene	15	nd–140	87
Hexachlorobenzene	110	0.15–1400	100
Pentachloroanisole	22.4	nd–340	33.3
trans-Chlordane	33.2	nd–190	87
cis-Chlordane	39	nd–250	87
oxy-Chlordane	0.04	nd–0.5	13
Heptachlor	0.6	nd–5.3	20
cis-Heptachloroepoxide	0.1	nd–0.6	27
trans-Heptachloroepoxide	0.4	nd–3.3	13.3
Aldrin	27	nd–354	93
Dieldrin	204	nd–1200	93
Endrin	1.1	nd–5	60
Endosulfan-I	150	nd–1310	87
Endosulfan-II	110	nd–1020	80
Methoxychlor	0.01	nd–0.1	6.7
Mirex	0.001	nd–0.02	6.7

nd = not detected, dw = dry weight

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Table 2: Concentrations of DDT, DDD and DDE in soil (mg/kg dw)

Sample point	Depth (cm)	4,4'-DDT	2,4'-DDT	4,4'-DDD	2,4'-DDD	4,4'-DDE	2,4'-DDE	Total DDT	(DDE+DDD)/DDT
A	10	31000	2800	270	220	3700	271	39000	0.1
B	5	120000	13000	5232	35	13300	380	152000	0.1
C	10	27200	340	404	473	5620	220	34300	0.2
D	5	8500	1122	800	9.3	1210	50.2	12000	0.2
E	200	17300	3300	63	33.2	930	57	22000	0.1
F	10	3200	362	210	103	2100	180	6200	0.7
G	200	16500	1900	401	244	3600	130	23000	0.2
H	10	40400	6442	3340	333	6000	280	57000	0.2
I	30	164	22.3	17.3	6.3	81	3.7	300	0.6
J	10	5700	2000	790	270	901	81	9700	0.3
K	10	3000	300	290	62	420	11	4000	0.3
L	10	12000	1200	810	293	640	29.1	15000	0.2
M	30	21000	3100	15000	2000	1520	74.2	43000	0.8
N	10	360	40.4	27	10.1	150	8.6	600	0.5
O	10	114000	7500	4300	2700	16200	620	150000	0.2

Very high concentrations of the DDT isomers and degradation products were found in samples from all the sampling points, indicating severe contamination at this site. The highest concentrations of DDT isomers and degradation products were found at sample points B (excavated store) and O (demolished building). The high concentrations of DDT isomers and degradation products found in soil samples collected from points E–H indicate that the concrete materials from the excavated store, which were dumped in open pits at points E and G were highly contaminated. Indeed, the excavated store (point B) was found to have the highest concentration of total DDT indicating severe contamination during the process of breaking the concrete floor for disposal.

There are strong positive correlations in the concentrations of the DDT isomers and their major degradation products ($r = 0.731–0.970$, $p < 0.01$, $df = 13$) indicating a common source. The relative distribution of DDT isomers and their degradation products in total DDT in soil at different sample points and depths is depicted in Figure 2.

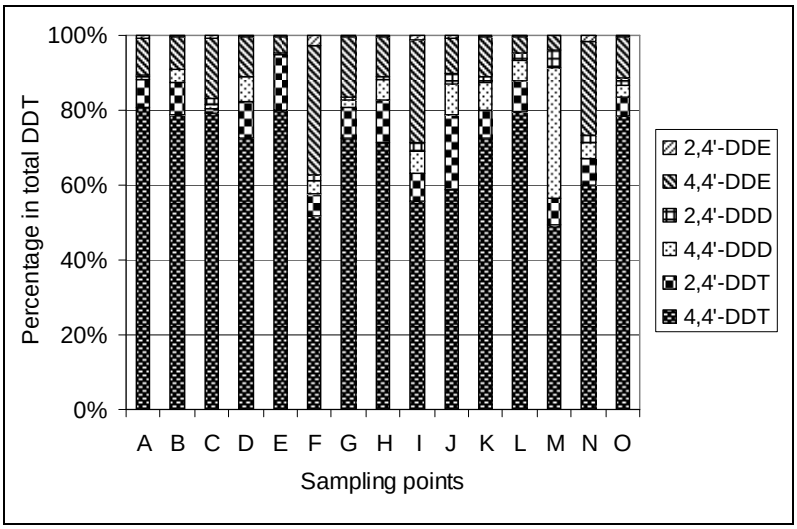

Figure 2 Distribution of DDT isomers and degradation products in total DDT in soil.

The composition of total DDT showed the following percentage distribution: 49.4–81% 4,4'-DDT, 1–20% 2,4'-DDT, 0.3–35% 4,4'-DDD, 0.02–5% 2,4'-DDD, 4–34% 4,4'-DDE, and 0.2–3% 2,4'-DDE. The average composition was: 70% 4,4'-DDT, 9% 2,4'-DDT, 6.2% 4,4'-DDD, 2% 2,4'-DDD, 14% 4,4'-DDE, and 0.7% 2,4'-DDE. 4,4'-DDT was the predominant contaminant in all samples. The composition of the total DDT is very similar to the composition of the technical DDT product obtained in the fabrication process (ATSDR, 2002), reflecting technical DDT as the source of contamination (Qiu *et al*. 2005) in the soil samples in the studied site.

The DDE/DDT ratios ranging 0.1–0.6 with an average of 0.2 were not significantly different from the DDD/DDT ratios, which ranged 0.01–0.7 with an average of 0.11, indicating that neither aerobic nor anaerobic pathway was favoured over the other. The (DDE+DDD)/DDT ratios ranged 0.1–0.8, with an average of 0.3 (Table 2), indicating that the DDT residues were not being significantly degraded (Zhang *et al*. 2006) in soil at the studied area.

Hexachlorocyclohexanes

Four HCH isomers α-HCH, β-HCH, γ-HCH, and δ-HCH were detected in 100% of the samples, while ε-HCH was detected in 33.3% of the samples. The concentrations of total HCH ranged from 2 to 8300 mg/kg dw. The highest concentrations of HCH isomers ranged from 164 mg/kg dw (ε-HCH) to 6900 mg/kg dw (α-HCH) (Table 3). The highest concentrations of HCH isomers were found in soil samples collected from point M, indicating that some of the plastic containers dumped at this area contained high amounts of HCH mixtures.

There are strong positive correlations in the concentrations of the HCH isomers ($r = 0.579–0.966$, $p < 0.05$, $df = 13$) indicating a common source.

The distribution of each isomer in total HCH in soil in each sample point is illustrated in Figure 3. The percentage distribution of HCH isomers in total HCH in all samples ranged as follows: 3–95% α-HCH, 1.4–48% β-HCH, 2–74% γ-HCH, 1–64% δ-HCH, and 0–11% ε-HCH. The average composition

was 36% α-HCH, 19% β-HCH, 22% γ-HCH, 22% δ-HCH, and 1.6% ε-HCH.

Table 3: Concentrations of HCHs in soil (mg/kg dw)

Sample point	Depth (cm)	α-HCH	β-HCH	γ-HCH	δ-HCH	ε-HCH	Total HCH	α-/ γ-HCH
A	10	202	20	27.3	3	2.7	260	7.4
B	5	0.5	2	14	2.4	nd	19	0.03
C	10	3.7	3	1.4	1.1	nd	9.2	2.6
D	5	0.4	0.32	2.8	0.4	nd	3.9	0.1
E	200	0.2	0.43	1	0.2	nd	1.8	0.2
F	10	0.7	1.1	0.8	3.3	nd	5.9	0.9
G	200	0.3	1.8	1	0.6	nd	3.8	0.3
H	10	1	1.2	0.3	0.9	nd	3.4	3.3
I	30	1	0.72	0.2	1.2	nd	3.1	6
J	10	1.5	8.5	10	25	4	49	0.2
K	10	0.5	1.9	0.5	7.5	1.3	12	1
L	10	2500	37.3	39.2	39	26	2600	63
M	30	6900	410	164	643	164	8300	42
N	10	26.4	4.2	2.5	5.9	nd	39	11
O	10	2100	510	120	310	nd	3040	18

nd: Not detected

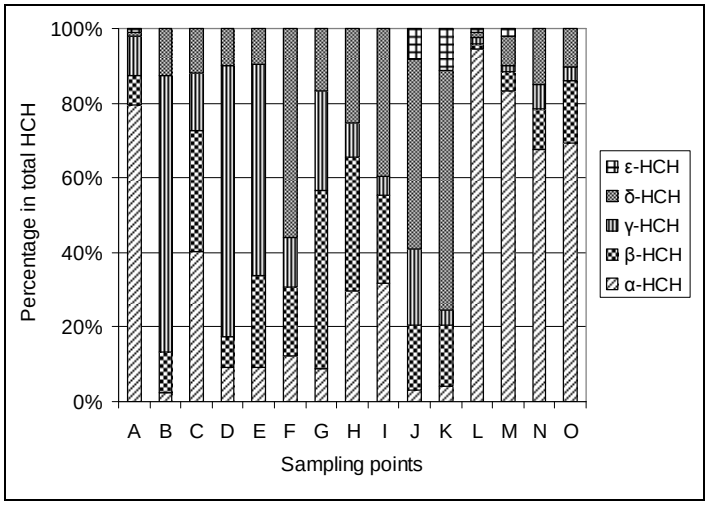

Figure 3: Percentage distribution of HCH isomers in total HCH in soil.

The composition of total HCH revealed a heterogenic nature. This may be related to the isomerization of HCH isomers during transformation process in soil as well as the differences in physico-chemical properties and degradation rates (Willett *et al*. 1998, ATSDR 2005). The α-HCH/γ-HCH ratios ranged 0.03–63, indicating both lindane and technical HCH as sources of HCH contamination in the studied area (ATSDR 2005, Gong *et al*. 2004). The α-HCH/γ-HCH ratios are comparable to those reported in Hong Kong soil (0.3–52) (Zhang *et al*. 2006).

Other Pesticides and Degradation Products

The following compounds were also detected in 6.7–100% of the soil samples at this site: pentachlorobenzene, hexachlorobenzene, pentachloroanisole, *trans*-chlordane, *cis*-chlordane, oxy-chlordane, heptachlor, *cis*-heptachloroepoxide, *trans*-heptachloroepoxide, aldrin, dieldrin, endrin, endosulfan-I, endosulfan-II, methoxychlor and mirex. Their highest concentrations varied from 0.02 mg/kg dw (mirex) to 1400 mg/kg dw (hexachlorobenzene) (Table 4). The concentrations of most of these compounds were very high. The highest concentrations of these compounds were mostly found in soil samples collected from point O and can be related to the residues of pesticides may be due to past storage or dumping in the demolished building. The detection frequencies and concentrations of pentachloroanisole, heptachlor, *cis*-heptachloroepoxide, and *trans*-heptachloroepoxide were generally very low suggesting that the contamination status of these compounds was attributed to background environmental sources there being no significant source for these compounds in the studied area. The concentrations of dieldrin were greater than those of aldrin, suggesting conversion of aldrin into dieldrin as one of its metabolites. Endosulfan was mainly represented as endosulfan-I in most samples, which is similar to the technical formulation (ATSDR 2000) indicating either old input without significant degradation or recent input may be due to recent application in the studied area or adjacent areas as there were ongoing agricultural activities such as maize cultivation

Table 4: Concentrations of other pesticides and degradation products in soil (mg/kg dw)

Sample point	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**
Depth (cm)	10	5	10	5	200	10	200	10	30	10	10	10	30	10	10
Pentachlorobenzene	0.8	nd	0.3	0.1	0.02	0.1	0.1	0.1	1	73.2	0.1	nd	2	2.9	140
Hexachlorobenzene	2.9	1.1	2.4	1.5	0.6	1.1	1.2	1.2	1.1	182	0.2	2.8	2.5	7.8	1400
Pentachloroanisole	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	340
trans-Chlordane	90	nd	131	nd	0.5	16.2	5.1	16	7.3	1.1	12	8.7	8	13.4	190
cis-Chlordane	74	nd	160	nd	0.6	20	3	13.3	8.5	0.7	17.4	8.2	8.6	20	250
oxy-Chlordane	nd	nd	nd	nd	nd	nd	nd	nd	0.13	nd	0.5	nd	nd	nd	nd
Heptachlor	5.3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.6	2.9	nd	nd
cis-Heptachloroepoxide	nd	nd	nd	*nd*	0.6	0.2	nd	nd	0.2	nd	0.34	nd	nd	nd	nd
trans-Heptachloroepoxide	nd	nd	nd	nd	3.3	nd	nd	nd	nd	nd	2.3	nd	nd	nd	nd
Aldrin	1.7	1.3	5.4	0.2	0.2	0.6	0.2	0.2	7.4	1.9	0.4	nd	0.4	25.1	360
Dieldrin	622	nd	510	3.1	6.4	72.2	23.2	70	20	47	61	200	200	40	1210
Endrin	3.2	nd	nd	nd	1	1.7	nd	1.1	0.14	0.9	0.5	3.7	4.5	nd	nd
Endosulfan-I	102	nd	250	nd	2.3	30	111	17	16.2	133	35	190	59	1.3	1310
Endosulfan-II	31	nd	4.7	nd	1.2	54	43	nd	1.7	230	12.2	232	21	2.1	1020
Methoxychlor	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.1	nd	nd	nd
Mirex	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.02	nd	nd	nd	nd

nd = Not detected

Distribution of the Compounds and Comparison with Maximum Limits

There were no significant differences in the average concentrations of pesticides and degradation products in soil among the sampling depths (5 cm, 10 cm, 30 and 200 cm) at 95% confidence level *(p =0.0892–0.8120)*, indicating a general even distribution of the compounds among the sampling depths. Although no analysis of the other matrices (water, vegetation and air) was conducted, the physico-chemical characteristics of the contaminants and local climate (the contaminated site is located in an area with a tropical climate where temperatures are always high, >30 ^{O}C) suggest that volatilization may be occurring, followed by atmospheric deposition to other areas at some distances from the source including the nearby residential areas and offices, or long-range atmospheric transport to great distances and contribute to regional or global distribution. The maximum permissible concentrations in soil for some of the compounds detected are DDT 3 mg/kg, HCHs 2 mg/kg, hexachlorobenzene 500 mg/kg, chlordane 0.6 mg/kg, heptachlor 0.2 mg/kg, aldrin 0.05 mg/kg, dieldrin 0.05 mg/kg, and endosulfan 60 mg/kg (TBS 2007). The concentrations of the compounds were generally far above these limits.

CONCLUSIONS

The dominant contaminants in soil at the former formulation plant in Morogoro were DDT, DDE, DDD, HCHs, endosulfans, hexachlorobenzene, dieldrin, chlordane, aldrin, pentachlorobenzene, heptachlor and endrin. Very high concentrations of these compounds were found in samples from all the sampling points, indicating severe contamination at the site. The compositions of total DDT and total endosulfan were similar to the technical formulations, indicating technical products as the sources of contamination. The results indicated that there was no significant degradation of the pesticides. The composition of total HCH indicated both technical HCH and lindane as the sources of contamination as well as isomerization of HCHs. The concentrations of dieldrin were greater than those of aldrin, suggesting conversion of aldrin into dieldrin. It is recommended that clean-up and proper disposal of contaminated soil, containers and concrete materials should be carried out.

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