STATUS OF PESTICIDES AND DEGRADATION PRODUCTS IN SOIL AFTER CLEAN-UP OF STOCKPILES AND TREATMENT WITH SODIUM HYDROXIDE AT A FORMER STORAGE SITE IN KOROGWE, TANZANIA

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ABSTRACT

The status of pesticide residues in soil samples collected from a former storage site one year after clean-up of stockpiles and treatment with NaOH was investigated. The analytes were extracted from samples 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:dichloromethane (1:1). Extra clean-up was performed through C18 SPE cartridges using acetonitrile as the eluting solvent. Labelled internal standards were used for identification and quantification. Analysis of the analytes was performed using a high resolution GC–MS. The dominant contaminants detected and their highest concentrations were 4,4'-DDT 423000 mg kg^{-1} dw, 2,4'-DDT 56200 mg kg^{-1} dw, 4,4'-DDD 41000 mg kg^{-1} dw, 2,4'-DDD 1300 mg kg^{-1} dw, 4,4'-DDE 30200 mg kg^{-1} dw and 2,4'-DDE 3000 mg kg^{-1} dw. The concentrations of total DDT ranged from 3 to 560000 mg kg^{-1} dw, with an average of 77000 mg kg^{-1} dw. Other compounds such as HCHs, pentachlorobenzene, hexachlorobenzene, pentachloroanisole, heptachloroepoxide, aldrin, dieldrin, endosulfan-II and methoxychlor were also detected, but their contamination status was attributed to environmental sources. The results indicated that the vertical movement of the compounds was very slow and that no significant degradation had occurred to the DDT residues in soil, implying risks and concerns for public health and the environment.

INTRODUCTION

Soil is an important reservoir for chemical contaminants and it generally acts as primary sink and emission source for contaminants. Soil contamination by pesticides plays an important role in the distribution of contaminants to other environmental compartments (Cousins *et al.* 1999). Leakage and accidents during storage and transportation of pesticides are usually responsible as point sources for soil contamination. This type of soil contamination involves high concentrations of the contaminants restricted to small areas favouring infiltration to the subsoil, placing risk to the underground water (Felsot *et al.* 2003). The intensity of the contamination depends on the levels of the contamination, the properties of the contaminants, soil composition (Spark and Swift 2002) and other environmental characteristics. Contaminations involving organochlorine pesticides are of great concern due to their high persistence in the environment and possible adverse health effects.

In many developing countries there are no cost-effective local options for pesticide disposal that are environmentally sound. In these cases, export to a country with a large-scale hazardous incineration plant is usually considered. Export is not necessarily an easy option because before shipment all the waste needs to be repacked and labelled in accordance with international treaties and recommendations for the international transport of dangerous goods, and national, regional or international regulations or agreements may form a barrier to export for disposal. International transport of

hazardous waste is governed by the Basel Convention on the control of transboundary movements of hazardous waste and their disposal and several similar regional conventions (e.g. the Bamako convention). Notification procedures prescribed by these conventions must be adhered to. The incineration company must have the approval of its government to import the waste for incineration (FAO 1996).

Chemical treatment is one of the options for disposal of pesticides. Chemical treatment can render certain groups of pesticides less toxic and safer to store, transport and dispose of. Some active ingredients can be destroyed by chemical treatment. A common method is hydrolysis, which is the reaction of a compound with water to break the bonds of the molecule. Alkaline hydrolysis, in which a strong alkaline substance such as sodium hydroxide or lime is added, can destroy some pesticides e.g. organophosphates and carbamates and greatly reduce their biological activity and environmental hazard. Acid hydrolysis works on some other groups of pesticides. However, there are several distinct limitations to the chemical treatment options: chemical treatment is difficult and dangerous, use of the wrong chemicals or procedures can produce violent reactions or highly toxic by-products and chemical treatment generally produces a greater volume of less toxic waste that still needs to be disposed of. Chemical treatment should only be done by a qualified professional (chemical expert) and then only if the treatment reduces toxicity to such an extent that the residue becomes suitable for a readily available disposal method (FAO 1996).

The objective of this study was to investigate the status of pesticides and degradation products in soil at a former storage site at Old Korogwe in Korogwe district, Tanzania, one year after clean-up of stockpiles and treatment with sodium hydroxide.

MATERIALS AND METHODS

The Study Area

The contaminated site at Old Korogwe has an area of bout 168 m^2 and is located within latitudes 4º 10' and 4º 20' S and longitudes 38º 45' and 38º 55' E in the former Korogwe Sisal Estate in Korogwe District-Tanga Region. The Old Korogwe Sisal Estate is owned by the Ministry of Agriculture and Food Security. The history of the contaminated site at Old Korogwe goes back to the 1980's when the Government of Tanzania was in the implementation of the policy well-known as "*Siasa ni Kilimo*" (Politics is Agriculture). The Government received large quantities of pesticides from donor countries and the common entry points of the consignments were Tanga and Dar es Salaam ports. Due to good accessibility and transport network by railway and roads, the Old Korogwe site was used as the storage place for stocks aimed for users in the Northern Zone of Tanzania. Therefore, large quantities of pesticides were stocked at that site waiting for distribution. Eventually, the Old Korogwe site contained at least 50 tonnes of obsolete pesticides which were poorly stored. The presence of large stockpiles of obsolete pesticides at that site was due to a number of factors which include; quantity received being more than the amount needed, inefficient distribution systems, inability of farmers to buy them and access to cheap illegally imported pesticides from neighbouring countries (Vice President's Office 2003).

The stockpiles of obsolete pesticides were dumped and left in open air in a generally poorly constructed old storage facility without appropriate attention for many years. In 1999, a shelter was constructed by the National Environment Management Council (NEMC) to keep the obsolete pesticides. The store, however, was still an

air open shed. The shelter was slightly improved by NEMC in 2003 by half-fixing the store sides with corrugated iron sheets, leaving the top half open. However, the storage status was still very poor since the packaging had been worn out leaving the bulk of pesticide powder subject to wind dispersion (Vice President's Office 2003). The site was remediated by complete removal of the pesticides and the store structure in January 2008 by GTZ (a German enterprise for sustainable development). The floor was cleaned by using sodium hydroxide. During the operation pesticides and other contaminated materials of about 110 tonnes were cleared and transported to Germany for disposal. The site is generally flat, but the surrounding area gradually slopes towards the Pangani River, which is located about 80 m from the site. The Pangani River pours its water into the Indian Ocean. Grazing of livestock around the contaminated site is common. The site is located close to drinking water sources and residential areas. Figure 1 shows the location of the study site.

Sampling

Soil samples were collected in January 2009 from the sampling points shown in Figure 2. The samples were collected at 10 cm depth (points A, C, D, E, H, I and J), 30 cm depth (points B and K), and 10 cm, 30 cm and 50 cm depths (points F and G).

Sampling was conducted applying standard guidelines (Åkerblom 1995). 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. 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.

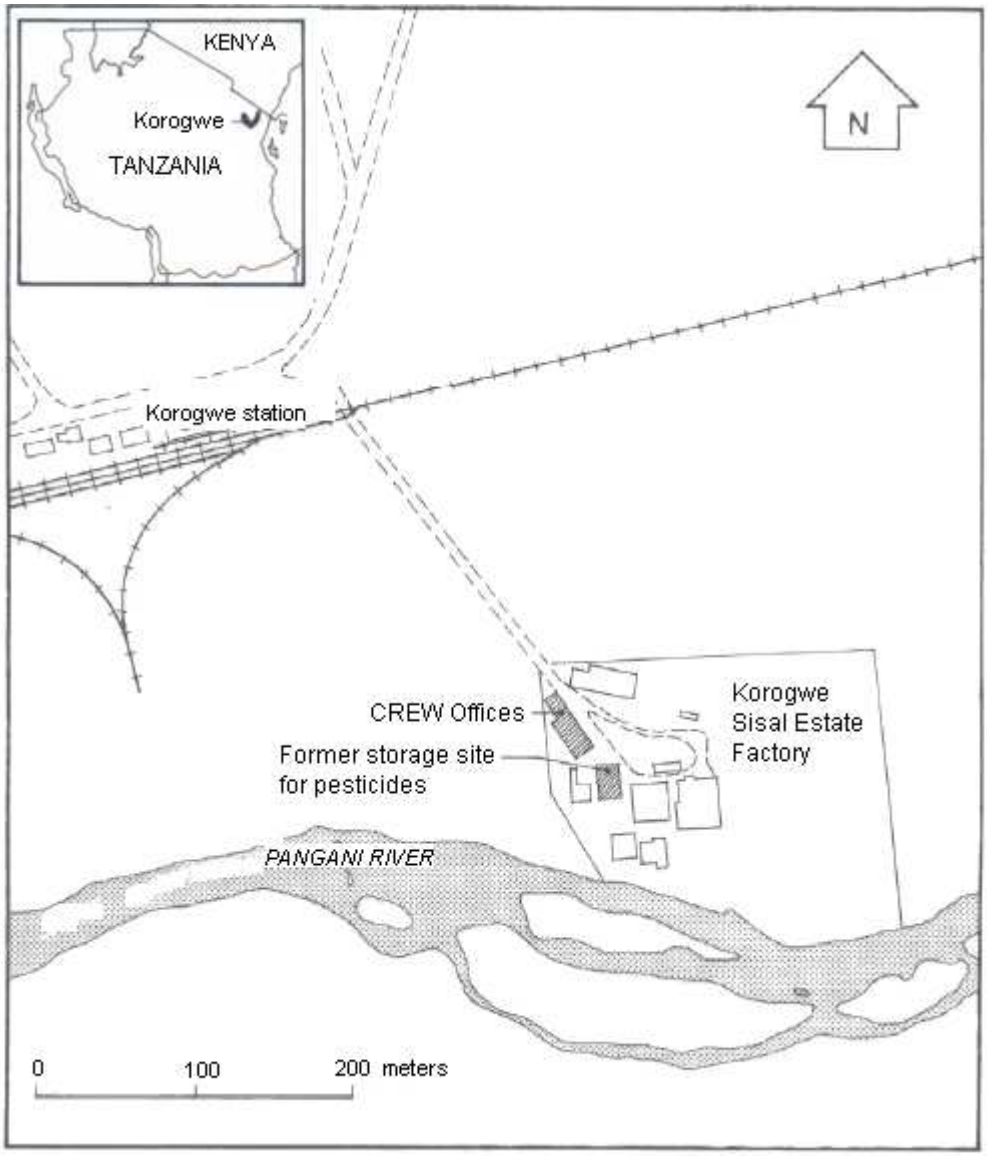

Figure 1: Map showing the location of the study site at Old Korogwe.

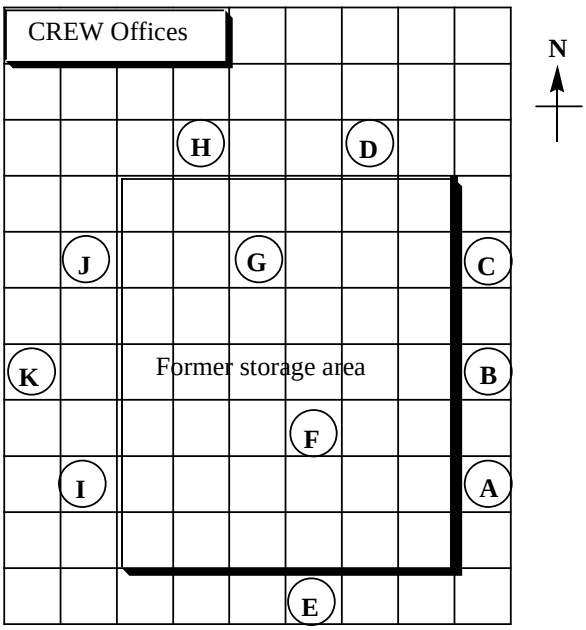

Figure 2: Map showing the sampling points at Korogwe. Each grid square = 2 x 2 m.

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, Munich-Germany in May–October 2009. The procedures by Schramm *et al*. (2008) were adopted with modifications. 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.

Clean-up of the extracts to remove interferences was conducted using silica gel and alumina in a glass column (30 cm long with an internal diameter of 2.5 cm) containing 10 g silica gel (grade 60), 5 g alumina with 3% H_2O and 5 g anhydrous sodium sulfate, packed in that order. During clean-up, 50–100 µl from the diluted sample extracts 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^{-1} 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^{-1}) 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 C_{18}-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^{-1} 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.

Instrumental 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^{-1} to 140 °C (0 min), 8 °C min^{-1} 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^{-1}, 280 °C, 5 min. The carrier gas was helium in a constant flow of 1.3 ml min^{-1}. 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 in separate deep freezers at –28 °C. All organic solvents were of picograde quality (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 ^{13}C-labelled and deuterated internal standards varied between 70% and 119% with average recoveries ranging from 78% to 105% (n = 15) and the coefficients of variation were in the range of 4–16%. The detection limit was defined as

three times the average noise value measured. The limits of detection ranged from 0.00001 to 0.0001 mg kg^{-1}. The limit of quantification was three times the limit of detection and every signal below this limit was treated as not detectable.

Statistical Analysis of Data

Statistical analysis of the data was performed by using GraphPad InStat software. The data were subjected to analysis of variance (ANOVA) to test for significance of differences followed by post hoc tests (Motulsky 1998).

RESULTS AND DISCUSSION

Pesticides and Degradation Products

The compounds detected in soil samples were dichlorodiphenyltrichloroethane (DDT) isomers and their major degradation products (dichlorodiphenyldichloroethane (DDD) and dichlorodiphenyldichloroethylene (DDE), hexachlorocylohexane (HCH) isomers, pentachlorobenzene, hexachlorobenzene, pentachloroanisole, heptachloroepoxide, aldrin, dieldrin, endosulfan-II and methoxychlor (Table 1).

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

Compound	Concentration (mg kg^{-1} dw)			Detection
	Average	Minimum	Maximum	Frequency (%)
4,4'-DDT	58000	1.5	423000	100
2,4'-DDT	8300	0.3	56200	100
4,4'-DDD	5500	0.01	41000	100
2,4'-DDD	220	0.01	1300	100
4,4'-DDE	5000	0.4	30200	100
2,4'-DDE	440	0.03	3000	100
Total DDT	77000	3	560000	100
α-HCH	3.6	nd	37	80
β-HCH	2.8	nd	26	93
γ-HCH	1.8	nd	20	66.7
δ-HCH	3.2	nd	47	60
ε-HCH	0.01	nd	0.2	6.7
Total HCH	12	0.001	130	100
α-/γ-HCH	1.8	0	8.6	80
Pentachlorobenzene	1.1	0.0001	14	100
Hexachlorobenzene	13	0.0002	183	100
Pentachloroanisole	2	nd	30	6.7
cis-Heptachloroepoxide	0.02	nd	0.2	13
trans-Heptachloroepoxide	0.04	nd	0.6	7
Aldrin	3.4	nd	51	27
Dieldrin	17	nd	250	80
Endosulfan-II	0.4	nd	5	20
Methoxychlor	0.01	nd	0.1	7

nd = not detected (below detection limit), dw = dry weight

DDT Isomers and Degradation Products

The concentrations of DDT isomers and their major degradation products (DDD and DDE) are presented in Tables 2. The DDT isomers and their degradation products were detected in all the samples. The concentrations of total DDT in samples varied between 3 and 560000 mg kg^{-1} dw.

In general, the highest concentrations of DDT isomers and degradation products varied between 1300 mg kg^{-1} dw (2,4'-DDD) to 423000 mg kg^{-1} dw (4,4'-DDT), with average concentrations varying from 220 mg kg^{-1} dw (2,4'-DDD) to 58000 mg kg^{-1} dw (4,4'-DDT) (Table 1). The average concentrations were in the order 4,4'-DDT > 2,4'-DDT > 4,4'-DDD > 4,4'-DDE > 2,4'-DDE > 2,4'-DDD.

Table 2: Concentrations of DDT, DDD and DDE in soil (mg kg^{-1} 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	2800	310	350	23	330	38	3800	0.2
B	30	1320	171	90	7.6	81	5.5	1700	0.2
C	10	1430	190	114	3.9	110	4.6	1900	0.2
D	10	121	21	28	0.6	41	1.3	213	0.5
E	10	1.5	0.3	0.01	0.01	1.1	0.03	3	0.6
F	10	180000	31310	12200	1300	11330	1300	233000	0.2
	30	11300	2400	2324	46	2000	180	18100	0.3
	50	2300	410	300	3.3	203	20.3	3230	0.2
G	10	423000	57000	41000	620	30200	3000	560000	0.2
	30	333	63.3	5.6	3.7	27	3.1	440	0.1
	50	2	0.6	0.2	0.1	0.4	0.04	3.2	0.3
H	10	171000	20000	23000	221	16000	753	230000	0.2
I	10	7120	860	1200	73	1600	81	11000	0.4
J	10	382	134	79	5.3	63	8.3	671	0.3
K	30	72000	13400	2300	1000	9900	1400	99200	0.3

There are strong positive correlations in the concentrations of the DDT isomers and their degradation products ($r = 0.712–0.988$, $p < 0.01$, $df = 13$) confirming a common source. The concentrations of total DDT were comparable to the findings at Vikuge, but were generally greater than those found in other studies in Tanzania (Kishimba *et al*. 2004). The concentrations of 4,4'-DDT and 4,4'-DDE were much greater than those reported at a contaminated site in Brazil (up to 7300 and 360 mg kg^{-1} dw, respectively) (Villa *et al*. 2006).

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 concentrations of total DDT in soil were far above the maximum permissible concentration, which is 3 mg/kg (TBS 2007). The highest concentrations of DDT isomers and degradation products were found at sample points F and G and this was not surprising because they were located inside the former storage area where stockpiles of the pesticides were kept. The concentrations of DDT isomers and degradation products had a trend of decreasing with increase in depth (points F and G). The concentrations of DDTs and degradation products in soil samples at 10 cm were significantly greater than those in samples at 30 cm depth, which in turn were significantly greater than those in samples at 50 cm depth ($p < 0.05$) suggesting that the vertical movement of these compounds was not significant.

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. The percentage distribution of DDT isomers and their degradation products in total DDT in all samples ranged as follows: 52–79% 4,4'-DDT, 7.9–20% 2,4'-DDT, 0.3–13% 4,4'-DDD, 0.1–2% 2,4'-DDD, 4.8–38.1% 4,4'-DDE and 0.2–1.4% 2,4'-DDE. The average composition was 69% 4,4'-DDT, 12% 2,4'-

DDT, 7.3% 4,4'-DDD, 0.6% 2,4'-DDD, 11% 4,4'-DDE and 0.8% 2,4'-DDE.

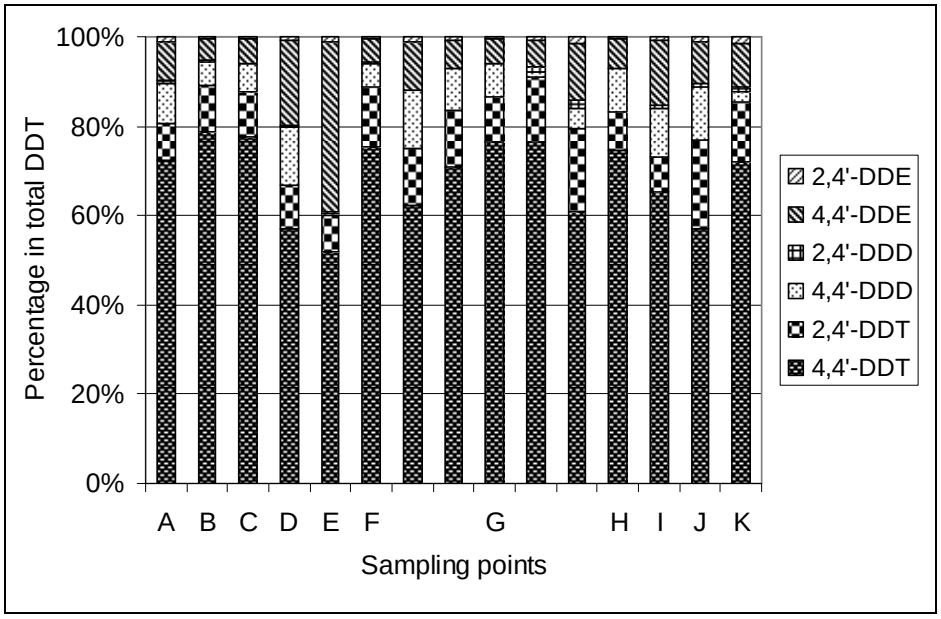

Figure 2: Distribution of DDT isomers and degradation products in total DDT in soil.

4,4'-DDT was the predominant contaminant in all the samples. The composition of the total DDT was very similar to the composition of the technical DDT product obtained in the fabrication process (ATSDR, 2002; Qiu *et al*. 2005), reflecting technical DDT as the source of soil contamination at the studied site. The (DDE+DDD)/DDT ratios ranged 0.1–0.6 (Table 2), indicating that no significant degradation occurred to the DDT residues (Zhang, *et al*. 2006). This shows that the clean-up and chemical treatment which were carried out at the studied site in 2008 were not very effective.

The compounds detected (DDT, DDD and DDE) are semi-volatile; since the contaminated site is located in the coastal area with a tropical climate where temperatures are always high (>30 ºC), it is possible that volatilization of the contaminants may be occurring, followed by atmospheric deposition to other areas at some distances from the source including the nearby river which runs to the Indian Ocean, or long-range transport through the atmosphere to great distances and contribute to regional or global distribution.

Other Pesticides and Degradation products

HCH isomers (α-HCH, β-HCH, γ-HCH, δ-HCH, and ε-HCH) were detected in 6.7–93.3% of the samples. The highest concentration of total HCH was 130 mg kg^{-1} dw (Table 3).

Table 3: Concentrations of HCHs in soil (mg kg^{-1} dw)

Sample point	Depth (cm)	α-HCH	β-HCH	γ-HCH	δ-HCH	ε-HCH	Total HCH	α-/γ-HCH
A	10	0.1	0.1	nd	nd	nd	0.2	>15
B	30	0.02	0.01	0.01	0.02	nd	0.1	2.0
C	10	0.02	nd	nd	nd	nd	0.02	>15

D	10	0.01	0.01	0.01	0.01	nd	0.03	1.0
E	10	0.0002	0.0003	0.0001	0.0003	nd	0.001	1.6
	10	nd	3.8	1.4	nd	nd	5.2	0
F	30	0.4	0.6	0.41	nd	nd	1.4	0.9
	50	0.03	0.14	nd	0.1	nd	0.3	>15
	10	6.5	5	nd	nd	nd	12	>15
G	30	9.5	0.5	1.1	0.8	0.2	12	8.6
	50	0.01	0.004	0.01	0.01	nd	0.03	1.0
H	10	nd	6	3.5	nd	nd	10	0
I	10	0.5	0.3	0.4	0.3	nd	1.5	1.3
J	10	nd	0.1	nd	0.04	nd	0.14	0
K	30	37	26	20	47	nd	130	1.9

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: 0–100% α-HCH, 0–73% β-HCH, 0–37% γ-HCH, 0–36% δ-HCH, and 0–1.8% ε-HCH. The average composition was 33% α-HCH, 36% β-HCH, 15% γ-HCH, 16% δ-HCH and 0.1% ε-HCH. The low α-HCH/γ-HCH ratios (0–2) in most samples indicated input of lindane, while high α-HCH/γ-HCH ratios (8.6–>15) in some samples suggest input of technical HCH from environmental sources or isomerization of HCH isomers during transformation process in soil (ATSDR 2005, Gong *et al*. 2004).

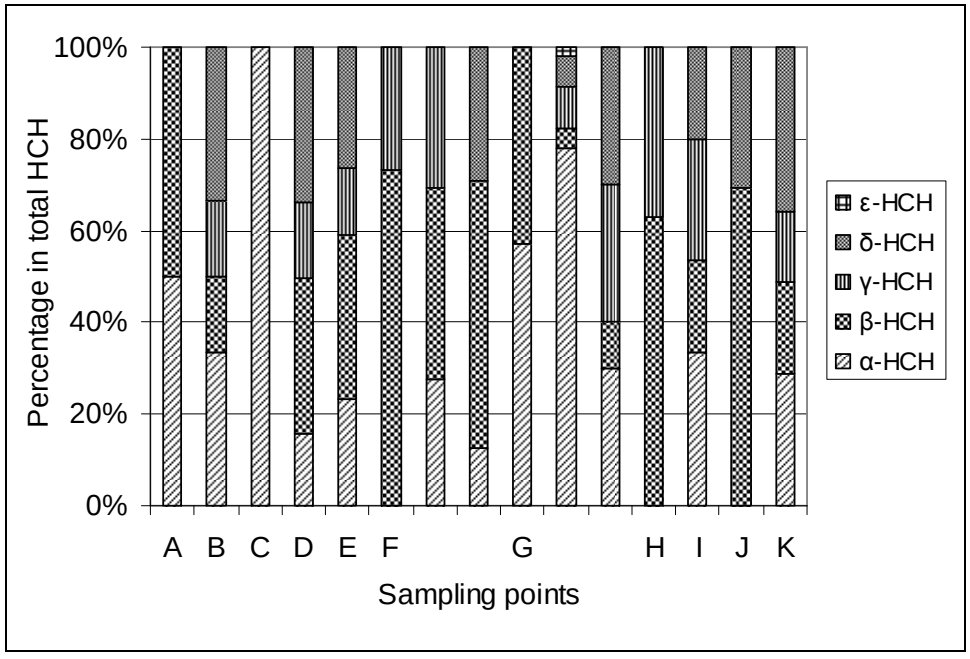

Figure 3: Percentage distribution of HCH isomers in total HCH in soil.

Other compounds which were detected in the samples at varying frequencies (6.7–100%) were: pentachlorobenzene, hexachlorobenzene, pentachloroanisole, *cis*-heptachloroepoxide, *trans*-heptachloroepoxide, aldrin, dieldrin, endosulfan-II and methoxychlor (Table 4). Their highest concentrations were as follows: pentachlorobenzene 14 mg kg^{-1} dw, HCB 180 mg kg^{-1} dw, pentachloroanisole 30 mg kg^{-1} dw, *cis*-heptachloroepoxide 0.21 mg kg^{-1} dw, *trans*-heptachloroepoxide 1 mg kg^{-1} dw, aldrin 51 mg kg^{-1} dw, dieldrin 250 mg kg^{-1} dw, endosulfan-II 5 mg kg^{-1} dw and methoxychlor 0.1 mg kg^{-1} dw. The highest concentrations of these compounds were mostly found in soil samples at point K (outside the former storage area), while they were rarely detected in samples from inside the former storage area (points F and G). It can be concluded that the source of these compounds was the background environment, and there was no significant source at the studied site i.e. they were absent in the stockpile that was stored at this site.

The concentrations of dieldrin were greater than those of aldrin in all the samples in which they were detected, indicating formation of dieldrin as a metabolite of aldrin (ATSDR 2002). Endosulfan-II was the only endosulfan isomer detected. The absence of endosulfan-I which is the larger component in technical formulation can be explained by the fact that endosulfan-I undergoes faster degradation than endosulfan-II in soils. Also, endosulfan-I is converted to endosulfan-II through isomerization (ATSDR 2000).

Table 4: Concentrations of other pesticides and degradation products in soil (mg kg^{-1} dw)

Sample point	A	B	C	D	E	F			G			H	I	J	K
Depth (cm)	10	30	10	10	10	10	30	50	10	30	50	10	10	10	30
Pentachlorobenzene	0.01	0.001	0.003	0.004	0.0001	0.40	0.2	0.01	1	0.52	0.003	1.1	0.2	0.01	14
Hexachlorobenzene	0.02	0.01	0.02	0.02	0.0002	2.4	2.7	0.04	2.3	3.2	0.04	2.2	2	0.02	180
Pentachloroanisole	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	30
trans-Chlordane	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
cis-Chlordane	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
oxy-Chlordane	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Heptachlor	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
cis-Heptachloroepoxide	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.21	nd	nd	0.11	nd	nd
trans-Heptachloroepoxide	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.6	nd	nd
Aldrin	nd	nd	nd	0.01	nd	nd	nd	nd	nd	0.7	0.003	nd	nd	nd	51
Dieldrin	0.02	0.01	0.01	0.11	0.0001	nd	nd	nd	nd	4.8	0.01	5.8	0.6	0.05	250
Endrin	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Endosulfan-I	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Endosulfan-II	nd	nd	nd	0.01	nd	5	nd	nd	nd	1.1	nd	nd	nd	nd	nd
Methoxychlor	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.1	nd	nd	nd	nd	nd
Mirex	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

CONCLUSIONS

The predominant contaminants were DDT, DDE and DDD. Other compounds were also detected in the samples, but the concentrations of these compounds were attributed to background sources. Very high concentrations of DDT, DDE and DDD were found in samples from all the sampling points. The highest concentrations of these compounds were found at sample points located inside the former storage area. The concentrations of DDT, DDE and DDD in soil samples decreased significantly with increase in depth (10 cm > 30 cm > 50 cm), suggesting that the vertical movement of these compounds was very slow. The results indicated that no significant degradation had occurred to the DDT residues.

It is recommended that additional remediation measures be carried out at the site e.g. by removal of the highly contaminated soil (0–10 cm) for treatment off site (by incineration or chemical treatments) or containment and remediation of the remaining contaminated soil by mixing it with clean soil, followed by composting or bioremediation on site.

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