A note on PCBs and chlorinated hydrocarbon pesticide residues in water, fish and sediment from the Olifants River, Eastern Transvaal, South Africa

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Abstract

Water, sediment and fish samples were collected from the Olifants River and analysed for 10 chlorinated pesticides and 2 polychlorinated biphenyls (Arochlors 1254 and 1260) during December 1990. A total of 31 fish representing 3 species were collected from the Loskop and Phalaborwa Dams. Water and sediment samples were collected from 11 sampling sites on all major tributaries on the Olifants River.

No polychlorinated biphenyls (PCBs) or chlorinated pesticides were detected in the water phase and the concentrations in the sediment were too low to confirm by mass spectrometry. Residues of DDT were found to be present in all the fish specimens collected. Levels of DDT were highest in *Eutropius depressirostris* and much lower in *Oreochromis mossambicus* and *Clarias gariepinus*.

The concentrations of DDT were lower than those reported in the literature and were within international criteria for the protection of aquatic life.

Introduction

Chlorinated hydrocarbon pesticides have been in use in South Africa since their development in the mid-1940s but their use was never as intensive as in Europe or North America, where serious environmental contamination problems have been encountered (Van Dyk et al., 1982). Despite this fact, nature conservation agencies of both the central and provincial administrations became progressively concerned about the potential effects on fish and birds in the late 1960s. Analyses of fauna from fresh water and marine environments were started in 1970 (Van Dyk et al., 1982). Although a number of research programmes have been conducted, the amount of data for Southern Africa is limited.

DDT was introduced to Southern Africa in 1945 for the control of malaria mosquitoes to increase production of crops such as maize and cotton (Van Dyk et al., 1982). The use of DDT as an agricultural stock remedy was severely restricted in 1970 and it was withdrawn as a stock remedy in 1974. In 1976 all sales ended except for malaria control by the State (Van Dyk et al., 1982). According to Davies and Randall (1989) approximately 121 t were still being used annually for malaria control in 1985 and circumstantial evidence suggests that considerable stockpiling for agricultural use took place. The use of dieldrin in South Africa was restricted in 1970, withdrawn as a stock remedy in 1974, restricted for use only as a moth-proofing agent, and for tsetse fly and harvester termite control during state emergency in 1979 and finally completely banned in 1982 (Van Dyk et al., 1982).

The very characteristics (high chemical stability) that made PCBs desirable commercial products cause their persistence in the environment. PCBs are not manufactured in South Africa and their presence can thus only be from industrial usage and the possible dumping of products containing PCBs (De Kock and Randall, 1984). It is therefore not surprising that the amount of data available on PCBs in the South African aquatic environment is very limited. Various international reports indicate that the amounts of PCBs in fish, birds and human tissue may still be on the increase, whereas the amounts of DDT are decreasing (Richardson and Waid, 1982).

It has been demonstrated that organochlorines are systematically concentrated in the upper trophic levels of animals. Continued PCB accumulation with continued exposure or increasing age has also been demonstrated by various authors (Baumann and Whittle, 1988). The decline in eggshell thickness provided the first evidence that the insecticide DDT or other organochlorines were largely responsible for declines of raptor populations in Europe and North America. Eggshell thinning in the South African fish eagle population has been reported by Davies and Randall (1989).

The Department of Water Affairs and Forestry initiated this study to investigate the presence of selected PCBs and chlorinated pesticide residues in 3 aquatic compartments (water, sediment and fish) in the middle and lower reaches of the Olifants River, E. Transvaal. DDT was specifically included because at the time of the study it was still used for malaria control in the lower reaches of the study area. The primary objective of the study was to determine the levels of PCBs and chlorinated pesticide residues in water, fish and sediment. A secondary objective was to determine whether recent contamination had occurred.

Study area

The Olifants River basin drains an area of about 54 500 km^2 between its source and the border between the RSA and Mocambique (Fig. 1). Since 1964/65, the cultivated area has consistently been about 24% of the area used for agriculture. In 1981, about 12% of the cultivated area, or 52 000 ha, was irrigated. At present, about 70 000 ha are irrigated in the study area. The middle portion of the Olifants River catchment which includes the Loskop and Rust de Winter Irrigation Schemes is a major cotton-producing region.

Sampling sites

Fish samples were collected at 2 points on Loskop Dam and one on the Phalaborwa Barrage. Water and sediment samples were collected from the 2 impoundments, from all major tributaries and from selected points on the Olifants River (Fig. 1).

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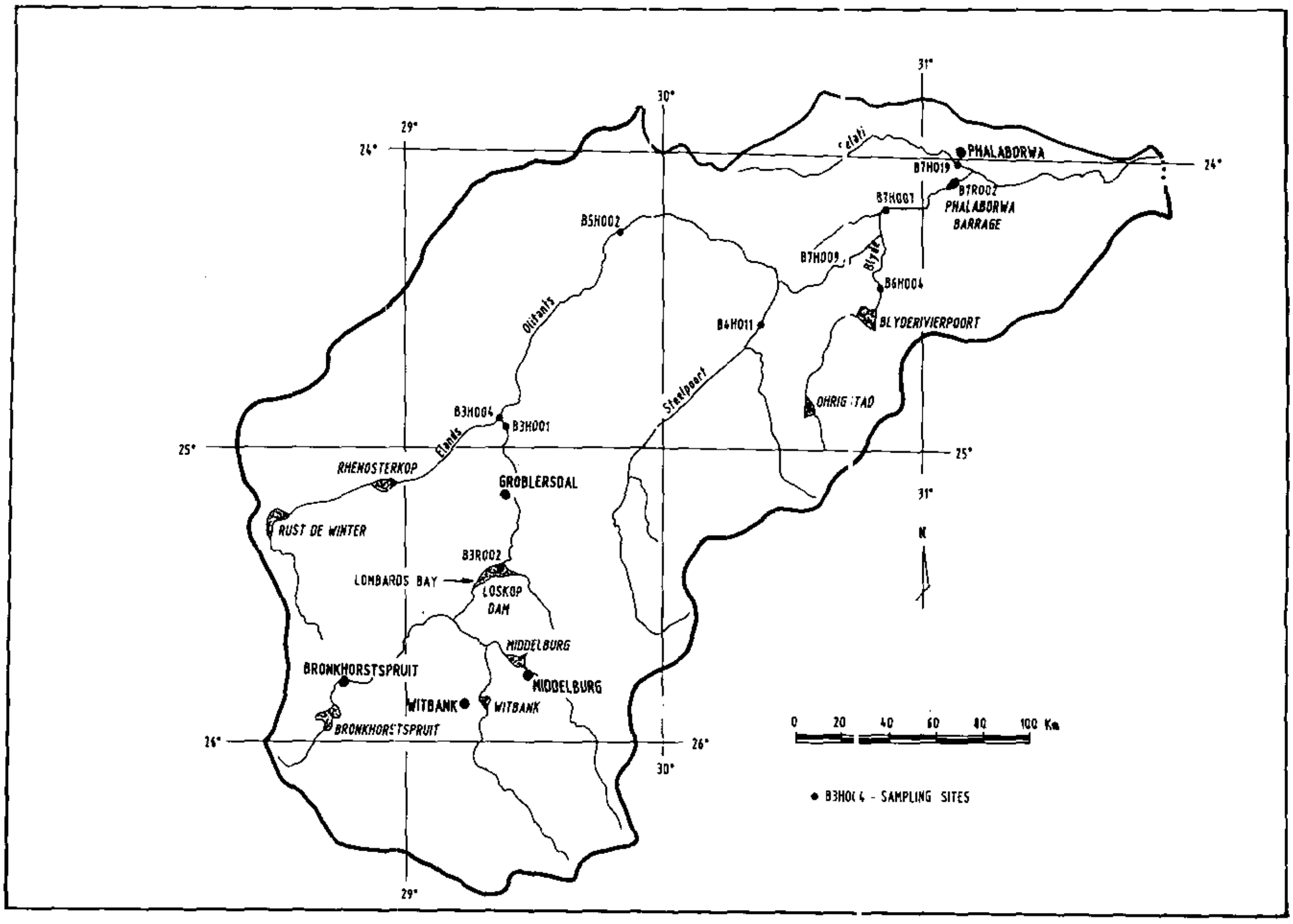

Figure 1
Sampling sites on the Olifants River and its major tributaries

TABLE 1 LIST OF COMPOUNDS ANALYSED FOR IN FISH AND SEDIMENT WITH THE CONCENTRATIONS OF THE STANDARD AS WELL AS THE METHOD DETECTION LIMITS (MDL)				
Compound	**Standard concentration µg/mℓ**	**Fish MDL µg/kg**	**Standard concentration µg/mℓ**	**Sediment MDL µg/g**
Lindane	0.033	0.069	0.22	0.001
Heptachlor	0.130	0.170	0.26	0.001
Endosulfan	0.048	0.200	0.24	0.001
Dieldrin	0.027	0.200	0.18	0.001
2,4-DDE	0.048	0.153	0.24	0.001
4,4-DDE	0.032	0.100	0.16	0.001
2,4-DDD	0.050	0.220	0.20	0.001
4,4-DDD	0.080	0.220	0.16	0.001
2,4-DDT	0.040	0.110	0.24	0.001
4,4-DDT	0.280	0.230	0.14	0.001

Materials and methods

Fish were collected overnight using gill nets. Three species, *Clarias gariepinus*, *Eutropius depressirostris* and *Oreochromis mossambicus*, which occur throughout the system and occupy different trophic levels in the food chain, were selected. Only larger specimens were selected in order to facilitate the detection of bio-magnification of insecticides. Scales and spines (dorsal and pectoral) were collected as indicators of age. The ages of *C. gariepinus* and *E. depressirostris* were determined by using spines (Perry, 1967; Donnelly and Caulton, 1969; and Bruton and Allanson, 1979).

The sharptooth catfish (*C. gariepinus*) is a benthic forager, feeding mainly at night on virtually any moving prey including insects, crabs, plankton, snails and fish, but also consumes young birds, rotting flesh, plants and fruits. The Mossambique tilapia (*O. mossambicus*) feeds mainly on benthic algae, especially diatoms, but adults also consume insects and crustaceans. The omnivorous butter catfish (*E. depressirostris*) feeds mainly on insects, shrimps, snails and fish as well as seeds, figs and the flesh of rotting carcasses (Bruton et al., 1982).

Fish were gutted and wrapped in aluminium foil and stored deep-frozen. Samples were transported to the laboratory at the Institute for Water Quality Studies (then the Hydrological Research Institute) where they were kept frozen. Table 2 summarises the data on the collected specimens.

Samples of the upper 15 cm of the sediment were collected with an Ekman grab sampler. Samples were kept frozen until analysis. Water samples were collected using a stainless steel bucket, and dispensed into 4.5 *l* glass bottles. Samples were preserved on-site with 4 m*l* concentrated sulphuric acid, and 100 m*l* dichloromethane were added to start the extraction. The bottles were sealed with aluminium foil-lined lids (DWAF, 1992).

Analytical procedure

Individual fish were scaled and decapitated and then homogenised using an electric meat mincer which had been pre-washed in RBS-35 soap solution and rinsed well with hot soap water. Subsamples (20 g) from individuals of a species were pooled and homogenised and 20 g of the composite sample was used for analysis.

The analytical procedure described in DWAF (1992) for PCBs in fish and sediment was used. The soxhlet extraction method was used for fish, liver and sediment samples, but a liquid-liquid extraction method with dichloromethane was used for water samples. The fish, water and sediment samples were analysed for 10 chlorinated pesticides and 2 PCBs (Table 1). The concentrations of the standards and the GC detection limits are given in Table 1.

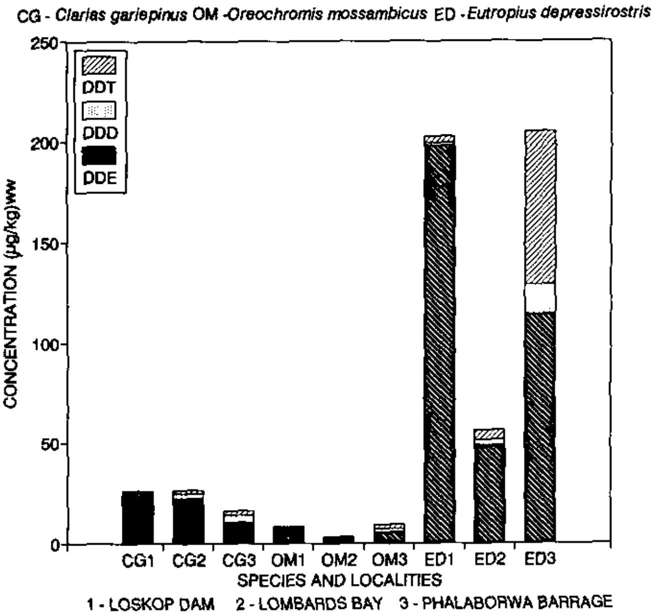

Figure 2
Concentrations of DDT, DDE and DDD in C. gariepinus, O. mossambicus *and* E. depressirostris *collected at Loskop Dam and Phalaborwa Barrage (expressed as µg/kg wet mass muscle)*

Results

Analytical results are summarised in Table 3. All concentrations above the detection limit, and confirmed by mass spectrometry, are indicated.

Fish

With the exception of 2 composite samples, DDT and its metabolites (DDE and DDD) were the only organochlorine pesticides (Table 3) detected in the fish samples. Heptachlor was found in only one sample but it could not be confirmed due to the low concentration. Arochlor 1260 was also detected in only one sample.

Body burdens of *C. gariepinus* and *O. mossambicus* were roughly comparable in all 3 sampling localities. The body burdens of *E. depressirostris* from Loskop Dam (Olifants inflow) and Phalaborwa Barrage were comparable and were about 4 times higher than the level in Lombards Bay.

Figure 2 illustrates the concentration of DDT, DDE and DDD within the 3 fish species. DDE and more specifically 4,4-DDE were almost the only metabolite detected in samples from both localities in the Loskop Dam. At the Phalaborwa Barrage, DDD and DDT, although lower in concentration than DDE, also contribute significantly towards the t-DDT value.

In order to normalise the residue levels obtained in this study, the concentrations were also expressed in terms of fish muscle lipid content (Table 3 and Fig. 3). Figure 3 illustrates the concentration of DDT, DDE and DDD expressed as concentration of the muscle fat. A similar pattern in terms of the contribution of the metabolites towards the t-DDT value is evident. In terms of the lipid content the body burdens within *E. depressirostris* are markedly higher.

Water

No PCBs or any chlorinated pesticides were detected in the water samples.

Sediment

Levels of contaminants in the sediment samples were too low for confirmation by mass spectrometry, except for 0.0286 µg/g 4,4-DDE in a sample from the Selati River (B7H019).

Discussion

Chlorinated hydrocarbon pesticides and PCBs are accumulated in fat layers of organs and tissue. The content of these products is normally higher in fish with a high fat content than in fish with a low fat content. This was furthermore demonstrated by various studies indicating differences between organs and tissues within an individual, with higher concentrations in the fatty tissue e.g. the abdominal fat (Heath, 1992; Monod and Keck, 1982). Higher concentrations are also reported for whole fish in comparison with fillets because whole fish samples contain more fat than fillet alone (Baumann and Whittle, 1988).

The levels of contamination for each species were approximately the same throughout the river system.

The fact that organisms higher up in the food chain seem to have increased body burdens of DDT and its metabolites (Table 3) indicates that the process of bioaccumulation is occurring in this system. The butter catfish had about 2 to 20 times higher levels of t-DDT than the other species from the same localities (Fig. 2).

In comparison with the DDD and DDT content, DDE was the highest in all the samples, although the concentration of DDT and metabolites in Phalaborwa Barrage differed from the other locali-

TABLE 2
FISH COLLECTED FROM LOSKOP DAM (B3R002) AND PHALABORWA BARRAGE (B7R002) IN DECEMBER 1990

Species	No	Standard length (mm)	Total length (mm)	Gender	Mass (g)	Age (years)
Loskop Dam						
Lombards Bay						
O. mossambicus	1	325	397	♂	1 150	5
	2	310	382	♂	1 125	4
	3	295	369	♂	1 075	3
	4	287	356	♀	900	5
	5	305	376	♂	975	4
E. depressirostris	1	315	375	♀	525	4
	2	274	330	♀	350	4
	3	248	300	♀	225	3
C. gariepinus	1	565	640	-	2 075	4
Olifants River inflow						
O. mossambicus	1	330	405	♂	1 650	4
	2	325	394	♂	1 050	5
	3	290	355	♀	1 150	4
	4	310	375	♀	1 550	3
	5	310	375	♀	1 050	4
E. depressirostris	1	250	300	♀	300	3
	2	210	255	♀	150	2
C. gariepinus	1	460	510	♂	1 100	4
Phalaborwa Barrage						
O. mossambicus	1	180	230	♀	350	3
	2	185	230	♀	350	2
	3	230	290	♂	500	3
	4	175	225	♂	300	2
	5	190	240	♂	350	1
E. depressirostris	1	315	385	♀	500	3
	2	280	342	♀	250	3
	3	280	340	♀	350	2
	4	265	330	♀	350	4
	5	255	313	♀	100	3
C. gariepinus	1	415	475	♀	850	3
	2	485	505	♀	100	4
	3	535	620	♂	1 800	5
	4	428	495	♂	1 000	1

TABLE 3
CONCENTRATIONS OF PCBs AND CHLORINATED PESTICIDES IN FISH COLLECTED FROM THE OLIFANTS RIVER (μg/kg WET MASS) (VALUES IN BRACKETS INDICATE CONCENTRATIONS AS mg/kg MUSCLE FAT)

Fish species	% Fat	PCB 1260	Hepta Chlor	2,4 DDE	4,4 DDE	2,4 DDD	4,4 DDD	4,4 DDT	t-DDT
Loskop Dam									
Olifants River									
C. gariepinus	1.17	n.d	n.d	<d.l	26.0 (2.22)	<d.l	<d.l	<d.l	26.0
O. mossambicus.	12.66	n.d	1.0 (7.90)	n.d	8.4 (0.066)	n.d	n.d	<d.l	8.4
E. depressirostris	3.99	41.0 (1.03)	<d.l	n.d	198 (4.96)	<d.l	1.4 (0.035)	2.9 (0.073)	202 (5.07)
Lombards Bay									
C. gariepinus	1.51	n.d	<d.l	n.d	22.2 (1.47)	<d.l	2.5 (0.017)	1.7 (0.013)	26.40 (1.75)
O. mossambicus	2.86	n.d	<d.l	n.d	3.1 (0.11)	n.d	n.d	n.d	3.10 (0.11)
E. depressirostris	5.46	n.d	<d.l	n.d	48.6 (0.89)	1.0 (0.018)	1.7 (0.031)	4.9 (0.09)	56.20 (1.03)
Phalaborwa Barrage									
C. gariepinus	1.28	n.d	n.d	n.d	10.2 (0.08)	<d.l	3.7 (0.29)	2.2 (0.17)	16.10 (1.26)
O. mossambicus	1.98	n.d	<d.l	<d.l	5.3 (0.27)	<d.l	1.9 (0.096)	2.2 (0.11)	9.40 (0.47)
E. depressirostris	5.84	n.d	<d.l	22.0 (0.38)	92.3 (1.58)	1.8 (0.03)	13.2 (0.23)	76.0 (1.30)	205 (3.52)

< dl - below detection limit
nd - not detected

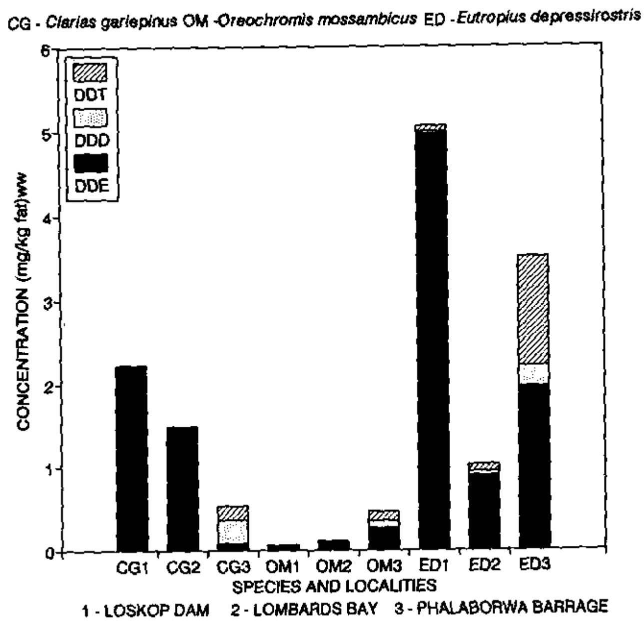

Figure 3
Concentrations of DDT, DDE and DDD in C. gariepinus, O. mossambicus *and* E. depressirostris *collected at Loskop Dam and Phalaborwa Barrage (expressed as mg/kg wet mass muscle fat)*

TABLE 4
COMPARISON OF t-DDT AND PCB LEVELS IN FISH FOUND INTERNATIONALLY WITH LEVELS FOUND IN SOUTHERN AFRICA (EXPRESSED AS μg/kg WET MASS)

Description	t-DDT	PCB	Reference
International			
Finnish Lakes-pike	10	50	*
Southern Baltic-cod	220-1 500	3 700-65 000	*
Antarctic fish species	300-1 900	80-770	*
Australian-Brisbane river-mullet	na	nd-2 900	*
Novia Scotia-Canada -striped bass	na	20	*
Saginaw Bay, Lake Huron	123	520	Miller and Jude, 1984
	479	409	
Lake Superior	30	Trace levels	Clark et al., 1984
Lake Michigan	610	1 930	
Lake Huron	410	1 950	
Lake Erie	170	1 070	
Lake Ontario	800	2 900	
Eastern Finland			
Vendace Kallavesi	23	315	Pyysalo et al., 1981
Suvasvesi	62	544	
Perch	333	814	
Roach	21	176	
Trout	19	180	
Median	**170**	**520**	
Southern Africa			
Wilderness Lake System	110	na	De Kock and Boshoff, 1987
Pongolo River Tigerfish	91.8	na	Bouwman et al., 1990
Blue Kurper	33.4	na	
Butter catfish	26.4	na	
Zimbabwe Sengwa	150	na	Matthiesen, 1985
Mwenda	120	na	(quoted by Bouwman et al., 1990)
Olifants River Catfish	22.8	nd	**This study**
Blue kurper	7.0	nd	
Butter catfish	154.6	nd	
Median	**91.8**		

na - not analysed
nd - not detected
* - references as quoted by De Kock and Boshoff, 1987

ties. A number of studies have shown the trend of DDT to degrade to DDE or DDD under aerobic or anaerobic conditions respectively (Chau and Afghan, 1982). A preponderance of DDT over its degradation products would therefore indicate a recent contamination of the environment with DDT (Butler et al., 1983). The differences between the Loskop Dam and Phalaborwa Barrage in terms of the ratio between DDT and its degradation products are evident from Fig. 2, indicating a more recent contamination in the Phalaborwa Barrage. A potential source of DDT could be malaria spraying and associated activities in the Phalaborwa Barrage catchment area. The presence of DDE would therefore indicate earlier contamination of the Loskop Dam catchment area.

PCBs consist of a large group of chlorinated biphenyls of which the Arochlors are the most common. There are approximately 10 Arochlors. The most common PCBs found in animal tissue are Arochlor 1254 and 1260 (Burgett and Basciani, 1985). These are 2 complex mixtures of PCBs whose total percentage is indicated in the last 2 digits of the Arochlor number. It has also been demonstrated that some PCBs are preferentially accumulated in biota, whereas others are excreted (Stevens, 1986).

It is difficult to compare the present results with other studies on the subject since little information is available, especially in the African context. This is further complicated by the lack of a consistent basis of calculation. Previous results from South Africa are based mainly on small localised collections and are difficult to compare with the present results. Van Dyk et al., (1982) pointed out that, with a few local exceptions, DDT-levels in all samples from South Africa seem to have been declining since 1974.

Table 4 compares the results with selected studies in South Africa and elsewhere. The median value has been used, in preference to the mean value because the listed data were not normally distributed. The results indicate that the current levels are much lower than the internationally reported levels. The results compare well with levels reported in South African systems.

Extreme t-DDT values for South Africa have been reported for a Mossambique tilapia (287) and spotted grunter (536 µg/kg wet mass) from the Kosi Bay system (Butler et al., 1983). The reappearance of DDT was reported in May 1987 in fish caught adjacent to the malaria control camp on Lake Nhlange, Kosi Bay (Sibbald, in Bouwman et al., 1990).

The acceptable daily intake (ADI) for human consumption of t-DDT determined by the FAO/WHO is 5 µg/kg body weight (WHO, 1979). Assuming a mean body weight of 60 kg and a daily fish consumption of 200 g, the intake calculated on a mean of 155 µg/kg t-DDT for the butter catfish is 0.5 µg/kg·d. At least 2 kg of fish must be consumed per day in order to exceed the ADI value. The toxicity hazard to humans of the DDT levels in the studied fish is therefore negligible.

The residue levels obtained for fish in this study can also be compared with those standards established for the protection of aquatic life in the USA (National Academy of Science and National Academy of Engineering, 1972). They recommend that whole body residues in fish muscle should not exceed 1 000 µg/kg (wet mass) for t-DDT or 500 µg/kg for PCBs. The levels found in this study were well below these standards.

The low levels of DDT contamination in the sediment can be explained in terms of the seasonal deposition of sediment in the impoundments. A new layer of sediment can be deposited with every runoff event, which prevents a build-up of contaminants in the upper layers of the sediment. The problems associated with the detection of contaminants in sediments are discussed by Miller and Jude (1984) and they conclude that the control of contamination in sediments is strongly limited by their different granulometric composition and by the repeated alteration of phases of transport and sedimentation.

The lack of historical data and comparative studies to detect trends in contamination levels and the effects of contamination on water-dependent organisms makes it difficult to draw any conclusions in this respect.

Conclusions

Residues of DDT and its metabolites are still present in fish throughout the system. Although the levels in fish are not particularly high and therefore do not constitute a health hazard in terms of fish consumption, it seems that DDT is continuing to enter the aquatic system as indicated by the ratio of DDT and DDE in specimens collected from the Phalaborwa Barrage.

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