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DDT residue concentrations and distribution in fish from Sanyati and Munyati river, Zimbabwe

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Abstract

DDT residue concentrations and distribution were assessed in sixteen species of fish collected from the Sanyati River (*B. lineomaculatus; H. vittatus; O. niloticus; O. mossambicus*) and Munyati River (L. *cylindricus; L. altivelis; M. longirostris; H. vittatus; T. rendalli; S. zambezensis; M. macrolepidotus; C. gariepinus; B. imberi; T. sparmanil; P. philander; M. salmoides*) in Zimbabwe. The selected fish maybe economically important to the local people and have potential for consumption. DDT was used frequently in this region for tsetse control and malaria control. Eighteen fish samples were analysed for DDT, ∑DDE, and DDE/DDT ratio. Furthermore, they were identified/quantified using identified/quantified using Gas Chromatography (GC), (Hewlett Packard GC 5890 series 11 with electron capture detector) and standard methods through microwave-assisted extraction. The highest concentration of ∑DDT was 0.017 mg/kg in Sanyati River for B. *lineomaculatus*. While the highest concentration of ∑DDT was 1.0 mg/kg in Munyati River for T. sparmanii. The DDE/∑DDT ratio is still substantially high different species for both rivers indicating persistent and long – term exposure. The ∑DDT (ppb) appeared to decline from the 1980s up to the current study. The concentration of total DDT compounds varied markedly amongst the different fish species. The guideline value of 0.02 mg/kg fresh weight by WHO/FAO was almost reached and exceeded in some fish species (*B. lineomaculatus* for Sanyati River and *T. sparmanii*, *L. cylindricus* and *L. altivelis* for Munyati River), therefore implying potential harmful public health effects on humans. Since the pollution of the fish samples was an indication of contamination of the river, the quality of the water for public water supply maybe of concern because of the indication of application of banned pesticides and bioaccumulation. Therefore, further monitoring of residues in Sanyati and Munyati rivers is recommended.

Keywords
DDT Residues, DDT Concentrations and Distribution, Sanyati and Munyati Rivers, Fish Species, Zimbabwe

Introduction

There have been contrasting perspectives on the use of DDT in many sectors leading to its impacts on the environment and untargeted organisms (Hlongwana *et al.,* 2013; Perdecini *et al.,* 2011). The impact of DDT on the environment has been persistent over the years since the advent use of extensive and intensive use of synthetic pesticides in agricultural activities (i.e., Cotton farming) and disease control (i.e., Malaria), (Van den Berg *et al.,* 2017; Perdecini *et al.,* 2011; Sibali *et al.,* 2009; Rao, 2007; Mahugija *et al.,* 2018) as well as tsetse control (Maruziva, 2016; Rayaisse *et al.,* 2011; Hargrove, 2003). At a global level there has been discontinued use of DDT for agricultural purposes, however for public health purposes the use of DDT

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still continues (Gasper *et al.,* 2017; Van den Berg *et al.,* 2017; Rao, 2007). DDT is one of 12 pesticides recommended by the WHO for indoor residual spray programs (EPA, 2021). Several studies have investigated the detection of DDT in water and sediments with limited expansion towards non targeted organisms such as fish species which have a close link to human consumption in Zimbabwe (Sibali *et al.,* 2009). Previous studies show that Organic pesticides such as Polychlorinated Biphenyls (PCBs) have been widely used for disease control since 1960s (Rao, 2007). Regulatory bodies at international scale seemed to approve the use of DDT as there was no effective alternative pesticide with a diverse impact of actions against vectors (Rao, 2007). However, the persistence of DDT in the aquatic environment led to a decline in its use at a global level since 1970s coupled with the need to adhere to the Stockholm Convention (Van den Berg *et al.,* 2017). DDT use was banned in all European Union member states in 1985 and has seen some species recover over time (Nygard *et al.,* 2019) while its use in the tropics has continued (Mendez *et al.,* 2016; Wandiga, 2011: Ritter *et al.,* 2011). DDT has been used for tsetse control in African countries such as Botswana, Cameroon, Chad, Ivory Coast, Kenya, Mali, Mozambique, Niger, Nigeria, South Africa, Uganda and Zambia (Van den Berg, 2009). In Zimbabwe, DDT use was registered in 1946 and by 1967, it was being used for Tsestse fly (*Glossina* sp.) control. In 1972, the use of DDT was extended to Malaria control while in 1973, the use of DDT in crop production was banned (Soko *et al.,* 2015). Furthermore, there was an official ban on the use of the pesticide in Zimbabwe except for research purposes in Tsetse and Malaria control (Soko *et al.,* 2015). The persistence of DDT has resulted in studies to determine its fate in the aquatic ecosystem and non-targeted organisms (Sibali *et al.,* 2009). DDE is a degradation product of DDT and the ratio of DDE to ∑DDT has been used as an indicator of how recent exposure has been (low ratio, recent exposure). While DDT is known to have deleterious effects in both humans and fish, in human, sub – lethal concentrations of DDT may result in impaired learning behaviour, slowed reflexes and a reduction in reproductive success (Bouwman *et al.,* 2012). In fish sub – lethal concentrations of DDT may result in disruption of cell membrane function and enzymatic systems (Shi et al., 2006). Other effects include increased egg mortality, reduced survival of fry (reduced recruitment), reduced food consumption as well as reduced food conversion efficiency (Zikankuba *et al.,* 2019). The 96 hr LC_{50}(ug/l) at 18^0C for northern pike (0.7g), Fathead minnow (1.2g) and Channel catfish (1.5g) was 2,7; 12.2 and 21.5. Observations show that Kafue Tilapia survived for 2 days when exposed to water containing DDT at a dilution of 1/36 000 000 (Mbewe *et al.,* 2016). Information on DDT toxicity (acute and chronic) in tropical fish species is very scanty, most data are on temperate species (Mbongwe, 2000). The Maximum Recommended Level (MRL) of DDT in food fish is 1mg/kg ∑DDT; while the maximum Allowable Daily Intake (ADI) is 0.02 mg/kg body weight (FAO/WHO, 1994). The World Health Organisation (WHO) presented a vector control statement on the continued use of DDT for the malaria control in the year 2006, especially for epidemic and endemic geographical locations (Sadasivaiah *et al.,* 2007). This position also received overwhelming support from international organisations championing the reduction of the Malaria burden of diseases as there had been observations that other treatment and control strategies were ineffective (Sadasivaiah *et al.,* 2007). However, this was contrary to the Stockholm Convention pronouncement in 2001 which targeted DDT as one of the Persistent Organic Pollutants intended to be phased out and ultimately eliminated. The position taken by WHO, therefore allowed for the provision DDT's continued use for indoor residual spraying and controlling for the disease vector. Furthermore, despite DDT being a low – cost anti – malarial tool, there are possible adverse impacts on human health and the environment leading to exposure through the Indoor Residual Spraying programmes that require a careful consideration to balance both the benefits and the negative impacts of Malaria control (Sadasivaiah *et al.,* 2007). The continued use of DDT has shown detrimental results to human health in previous studies based on factors such as length of stay in sprayed areas and the age of the populations affected (Koepke, 2004). DDT is an organochlorine compound which has characteristics of hydrophobicity and lipophilicity which require organic solvents such as fat and oil as vehicles for catalysis (Burr, 2014). Observations show that DDT accumulates in all tissues of the organisms, however more significantly in adipose tissues (Burr, 2014). Previous studies have shown that lactating mothers

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may excrete up to 10% of DDT doses via breast feeding (Burr, 2014). DDE is more strongly bound in tissues than DDT, while the half – life of DDT in human beings is between 3 – 6 years and twice as long for DDE (Burr, 2014). Hence, the objectives of the study were to determine the DDT concentrations, the DDE/∑DDT ratio in fish from Sanyati River. The study was also aimed at determining whether the observed DDT concentrations in fish posed a health hazard to humans in terms of recommended levels in food fish. Furthermore, concentrations of DDT in fish from Sanyati River were compared with those of fish in Lake Kariba and Lake Chivero (formerly Lake McIlwaine). The Sanyati River is the largest tributary river flowing into the Lake Kariba after the Zambezi River. The Sanyati River contributes about 10% of the annual inflow into the Lake (Mhlanga, 2000). The Sanyati River has two main tributaries; the Munyati and Mupfure rivers. The catchments of the tributary rivers include agricultural land (mainly crop and livestock farming) as well as National Parks and Safari areas.

The catchment is bordered by areas as far as Magunje, Alaska, Selous, Mahusekwa, Chivhu, Mvuma, Gweru, Gokwe, Lusulu up to Lake Kariba. The border covers four Provinces which are Mashonaland West, Mashonaland East, Midlands and Matebeleland North. Major rivers that drain into Sanyati River are Munyati, Muzvezve, Sebakwe, Kwekwe and Mupfure. The major towns serviced by the Catchment are Gweru, Kwekwe, Kadoma, Chegutu, Gokwe, Chivhu and Mvuma (Zinwa, 2021 https://www.zinwa.co.zw/catchments/sanyati-catchment). The lower reaches of the Sanyati flow through a low – lying, low rainfall area which is part of the Zambezi Valley. The Zambezi Valley has a high prevalence of mosquitoes and Tsetse fly. Sampling was carried out at Munyati River and at Sanyati River Bridge. The sampling site on Munyati River was in a mining and agricultural farming locality. Sanyati River Bridge sampling site was in the Zambezi Valley area (see Figure 1).

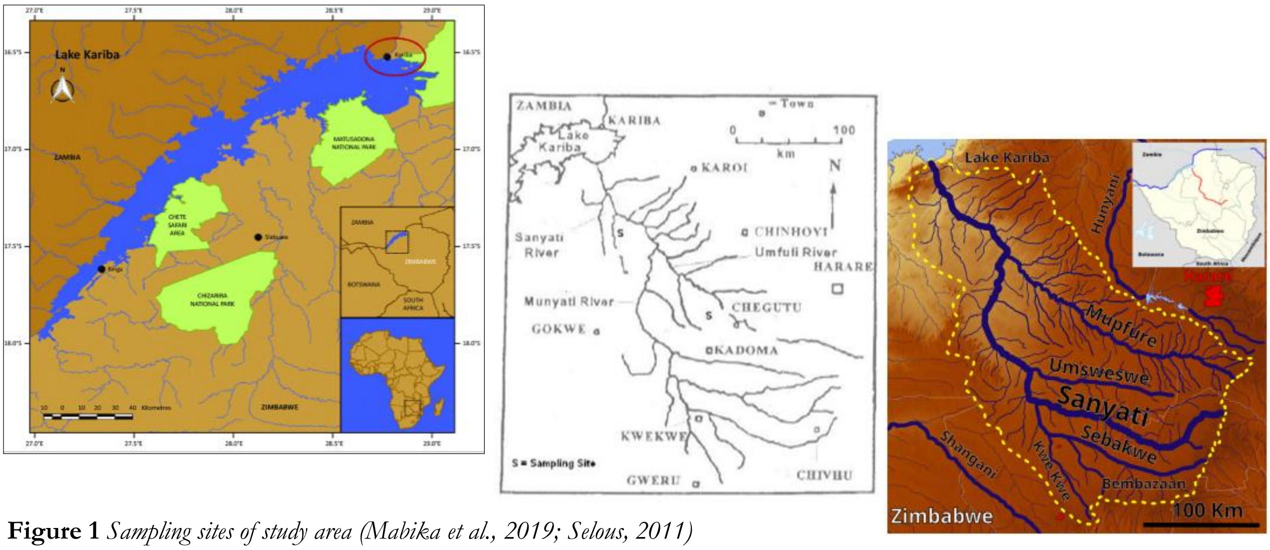

Figure 1 *Sampling sites of study area (Mabika et al., 2019; Selous, 2011)*

Materials and Methods

The onset of the sampling was carried out in November 2001 with Gill nets being used to catch the fish. The fish samples were collected in November 2001 and were selected considering the species and length. For each species, fish samples of various sizes (lengths). The descriptions of the samples selected among the fish species were based on local name, scientific name and length. A total of 18 fish samples were analysed. Information recorded for each individual fish included Species name and total length. The residue analysis was carried out using four basic steps; (i) sample preparation, (ii) pesticide extraction, (iii) clean – up /purification of the extract and (iv) determination of pesticide levels through gas chromatography. The extraction process involved the use of anyhdrous Sodium Sulphate (Hexane by Soxhlet). Clean – up was done using Hexane Residue.

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content was determined by Gas Chromatography. Analysis was done on a Varian Model 3400 Cx (Electron Capture Detector) fitter with a Chromjet Integrator. Separation was done with a Silica capillary column. Ultra High Purity Nitrogen carrier gas was used at a low rate of 5 ml/min (making up Nitrogen at 45 ml/min). The injector temperature was at 220^{0}C while Electron Capture Detector temperature was 300^{0}C. Validation was done using two reagent blank samples and two samples spiked with known levels of pesticide.

Results and Discussion

The mean ∑DDT concentration was relatively in the same range for the four species (0.003 – 0.017) mg/kg Table 1 and 2). This was less than other studies on Tilapia (Jurgens et al., 2016) elsewhere. However, the findings were similar to other studies (Mahugija *et al.,* 2018; Kiziewicz and Czeczuga, 2003) indicating risks for public health and the environment such as dietary exposure and the risk of DDT concerning freshwater fish aquaculture (Kasza *et al.,* 2020).

Table 1. *∑DDT Residue Concentrations (mg/kg) at Sanyati River Bridge (Authors' findings)*

Common Name	Scientific Name	Mean Length (Range)cm	Mean ∑DDT Concentration (Range)	DDE/∑DDT Ratio	n
Line spotted Barb	B. lineomaculatus	-	0.017 (0.01 – 0.03)	1	3
Tigerfish	H. vittatus	23.05 (23 – 23.1)	0.01	1	2
Nile Tilapia	O. niloticus	24.9 (19.7 – 33.5)	0.003 (0 – 0.1)	1	3
Mozambique Tilapia	O. mossambicus	26.2 (20.5 – 39.8)	0.01 (0 – 0.06)	0.375 (0 – 1)	8

Table 2. *∑DDT Residue Concentrations (mg/kg) at Munyati River (Authors' findings)*

Common name	Scientific name	Mean Length (Range) cm	Mean ∑DDT Concentration (Range)	DDE/∑DDT Ratio	n
Red – eye Labeo	L. cylindricus	18.8 (9.2 – 23.5)	0.02 (0.0 – 0.09)	0.732 (0.464 – 1.0)	5
Manyame Labeo	L. altivelis	25.3 (20.5 – 30.1)	0.025 (0.02 – 0.03)	1	2
Eastern Bottlenose	M. longirostris	33.8	0	0	1
Tigerfish	H. vittatus	28.5 (16.7 – 36.5)	0.01	1	5
Red – Breast Bream	T. rendalli	23.5 (19.6 – 28.5)	0	0	3
Brown Squeaker	S. zambezensis	21.4 (20.5 – 22.4)	0.01 (0 – 0.02)	1	3
Bulldog	M. macrolepidotus	22.7 (18.7 – 27.2)	0	0	3
Sharptooth Catfish	C. gariepinus	53 (32.4 – 68)	0	0	3
Imberi	B. imberi	18.8 (18.3 – 19.3)	0	0	2
Banded Tilapia	T. sparmanii	4.1	1	1	2
Southern Mouthbrooder	P. philander	8.4	0	0	1
Largemouth Bass	M. salmoides	21.4 (20.5 – 22.4)	0.01 (0 – 0.02)	1	3

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However, previous studies show that the impact on fish consumers was observed to be limited at these levels (Kasza *et al.,* 2020). The highest mean ∑DDT was for the Line spotted Barb (B. lineomaculatus) which has been observed to be above other levels in previous studies just as the present study (McCarton and Mhlanga, 2003) in the same pattern as previous studies. No DDT was detected in the water from Sanyati River Bridge, hence the use of the water may have a good indication for healthy crops and livestock (Ochoa – Riveiro *et al.,* 2017). The DDE/∑DDT ratio was high for three species as compared to the anticipated targets (Aguilar, 1984). The high ratio indicates recent exposure in and around Sanyati River, a pattern that has also been observed in other studies (Aguilar, 1984). The guideline value of 0.02 mg/kg fresh weight by WHO/FAO was almost reached by some fish species (B. lineomaculatus), an undesirable level for fish consumption impacting on human health. The mean ∑DDT concentration was relatively in the same range for the four species (0 – 1.0) mg/kg. The range of concentration was similar to previous studies elsewhere (Mahugija *et al.,* 2018; Ezemonye *et al.,* 2015; Kiziewicz and Czeczuga, 2003; Bagumire *et al.,* 2008) indicating risks for public health and the environment. Furthermore, the concentrations appeared to be similar to those of Sanyati River. The highest mean was 1.0 mg/kg for Banded Tilapia (*T. sparmanii*). The DDT concentration found in Banded Tilapia maybe attributed to historical sources as observed in previous studies (Ding et al., 2020). However, there were no DDT concentrations detected in the water from Munyati River. The DDE/∑DDT ratio was high for six species as compared to the anticipated targets (Aguilar, 1984). This could mean there is a possibility of more pollutant input into the ecosystem in and around Munyati River as observed in other studies (Aguilar, 1984). The guideline value of 0.02 mg/kg fresh weight by WHO/FAO (1994) was almost reached and exceeded by some fish species (*T. sparmanii*, *L. cylindricus*; *L. altivelis*). This generates a narrative of possible impacts if the use of respective pollutants is not discontinued.

Table 3. *Comparison of ∑DDT residue concentrations (ppb) in fish from Lake Chivero, Lake Kariba and Sanyati River*

Common name	Scientific name	∑DDT (ppb)	Locality (Year)	References
Manyame Labeo	L. altivelis	1100	Chivero (1987 – 88)	Mhlanga and Madziva (1990)
Manyame Labeo	L. altivelis	6590	Kariba Gache – Gache (1990)	Berg et al. (1992)
Manyame Labeo	L. altivelis	4350	Kariba Kasese (1990)	Berg et al. (1992)
Manyame Labeo	L. altivelis	25	Sanyati River (2001)	This study
Redbreast Tilapia	T. rendalli	790	Chivero (1987 – 88)	Mhlanga and Madziva (1990)
Redbreast Tilapia	T. rendalli	2110	Kariba Kasese (1990)	Berg et al. (1992)
Redbreast Tilapia	T. rendalli	0	Sanyati River (2001)	Resumption of field work of this study
Greenhead Tilapia	O. macrochir	230.5	Chivero (1992)	Moyo and Mafara (1997)
Kariba Bream	O. mortimeri	3190	Kariba Kasese (1990)	Berg et al. (1992)
Mozambique Bream	O. mossambicus	0	Sanyati River (2001)	This study
Tigerfish	H. vittatus	2780	Kariba Butete (1990)	Berg et al. (1992)
Tigerfish	H. vittatus	4360	Kariba Gache Gache (1990)	Berg et al. (1992)
Tigerfish	H. vittatus	7670	Kariba Chibuyu (1990)	Berg et al. (1992)
Tigerfish	H. vittatus	1000	Chivero (1987 – 88)	Mhlanga and Madziva (1990)
Tigerfish	H. vittatus	10	Sanyati River (2001)	This study

The mean ∑DDT concentration (ppb) had a wide range and difference in concentration across various types of fish. Manyame Labeo (*L. altivelis*) recorded the highest concentration in 1990. This could have been due to the recency of exposure to DDT as observed in previous studies (Soko *et al.,* 2015). The current study shows non detectable and low concentration levels for Redbreast Tilapia, Mozam-

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bique Bream and Tigerfish which may imply an improved recovery rate of the natural environment after the ban of the use of DDT (Nygard *et al.,* 2019). However, there is a general decline in ∑DDT concentration (ppb) with the recency of the studies investigated in Zimbabwe around the Sanyati Catchment area. There were no DDT concentrations detected in the water from Munyati River. The decline and the non – detectable levels of DDT concentration in the fish species, however does not clear the fish species for edibility as there could be other possible food safety related pollutants (i.e. total bacteria, heavy, aflatoxins, fungal counts and E. coli O157:H7) that may contaminate the rivers and lead to human health hazard exposure as observed in other studies in Zimbabwe (Ouma *et al.,* 2022: Manjengwa *et al.,* 2019).

Conclusions

Findings from the study show that ∑DDT residue concentration in fish ranged from 0 – 0.09 mg/kg. Apart from the Mozambique Bream (O. mossambicus), the DDE/∑DDT ratio was generally high, suggesting long - term exposure with a possibility of recency in exposure. Overall DDT residue concentrations observed in this study were below the maximum Allowable Daily Intake (ADI) in fish available for consumption by humans. However, this does not reflect on letting the guard down as there could be indicating risks for public health and the environment such as dietary exposure and the risk of DDT as observed in studies elsewhere. In light of the above, toxicity studies have to be carried out on indigenous fish species to determine the chronic and acute effect of DDT residue concentrations occurring in the local environment. Furthermore, there are other concerns with regard to food safety and water pollution aspects which may need to be evaluated for a holistic perspective of managing pollutant spread and levels in water bodies where fish species are found. Residue concentrations observed in this study were lower than those observed in similar species in Lake Chivero and Lake Kariba. However, the DDE/∑DDT ratio was of concern in the context of surpassing the anticipated indicative goal. This may imply that there is a need to assess the chronology of pollutants which may still be inputs into the ecosystem. Furthermore, the advent of artisanal mining may exacerbate pollution levels and impacts on both water sources and fish species in contaminated water bodies. Hence continuous monitoring is still required in order to ensure that there are no new inputs of DDT that may contaminate the environment, as well as affect non – target organisms and humans.

Data availability, financial support statement and acknowledgements

The data is available in the Lake Kariba Fisheries Research Institute repository, not necessarily in the format of presented in the article.

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Declaration of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

References

AGUILAR A. (1984) Relationship of DDE/ΣDDT in Marine Mammals to the Chronology of DDT Input into the Ecosystem. Canadian Journal of Fisheries and Aquatic Sciences. 41(6): 840-844. https://doi.org/10.1139/f84-100

BAGUMIRE A., RUMBEIHA W.K., TODD E.C., MUYANJA C., NASINYAMA G.W. (2008) Analysis of Environmental Chemical Residues in Products of Emerging Aquaculture Industry in Uganda as Case Study for Sub-Saharan Africa. Food Addit Contam Part B Surveill, 1(2):153-60. https://doi.org/10.1080/02652030802482491

BERG H., KIIBUS M., KAUTSKY N. (1992) DDT and other insecticides in the Lake Kariba Ecosystem, Zimbabwe. Springer Nature, 21(7):444 – 450.

BOUWMAN, H., KYLIN, H., AND BORNMAN, M. (2012). The Paradox of the effectiveness of IRS Insecticides (Including DDT) and Its Impacts on Human Health - What Can We Fix If It Isn't Broken? Malaria Journal, 11 http://dx.doi.org/10.1186/1475-2875-11-S1-P14

BURR S.A. (2014) DDT (Dichlorodiphenyltrichloethane). Encyclopedia of Toxicology (Third Edition). Academic Press, 1141-1143. https://doi.org/10.1016/ B978-0-12-386454-3.00122-6.

DING Y., WU Z., ZHANG R., KANG Y., YU K., WANG Y., ZHENG X., HUANG L., ZHAO L. (2020) Spatial Distribution, Source Identification, and Risk Assessment of Organochlorines in Wild Tilapia from Guangxi, South China. *Sci Rep* **10,** 15179 (2020). https://doi.org/10.1038/s41598-020-72160-x

EPA (2021) DDT-A Brief History and Status. https://

DOI: 10.6092/issn.2281-4485/18393

www.epa.gov/ingredients-used-pesticide-products/ddt-brief -history-and-status Accessed 5 September 2021.

EZEMONYE L.I., OGBEIDE O.S., TONGO I. ENUNEKU A.A., OGBOMIDA E. (2015) Pesticide Contaminants in Clarias Gariepinus and Tilapia Zilli from Three Rivers in Edo State, Nigeria; Implications for Human Exposure. Food Contamination **2**:3. https://doi.org/10.1186/s40550-015-0009-z

FAO/WHO (1984) Pesticide Residues in Food. Joint report of the FAO Panel of Experts on Pesticide Residues in Food and the Environment (Geneva).

GASPAR F. W., CHEVRIER J., QUIRÓS-ALCALÁ L., LIPSITT J. M., DANA B. B., HOLLAND N., ESKENAZI B. (2017) Levels and Determinants of DDT and DDE Exposure in the VHEMBE Cohort. Environmental Health Perspectives (Online), 125(7) http://dx.doi.org/10.1289/EHP353

HARGROVE J.W. (2003) Optimized Simulation of the Control of Tsetse Flies Glossina Pallidipes and G. M. Morsitans (Diptera: Glossinidae) Using Odour-Baited Targets in Zimbabwe. Bulletin of Entomological Research, 93(1):19-29. http://dx.doi.org/10.1079/BER2002205

HLONGWANA K.W., MAVUNDZA E.J., MOHAPI E. P., KRUGER P., URBACH J., MUKARATIRWA S., MAHARAJ R. (2013) Vector-Control Personnel's Know ledge, Perceptions and Practices towards Insecticides used for Indoor Residual Spraying in Limpopo Province, South Africa. Parasites & Vectors, 6:118. http://.doi.org/10.1186/ 1756-3305-6-118

https://www.zinwa.co.zw/catchments/sanyati-catchment/

JÜRGENS M.D., CROSSE J., HAMILTON P.B., JOHNSON A.C., JONES K.C. (2016). The Long Shadow of our Chemical past – High DDT Concentrations in Fish near a former Agrochemicals Factory in England. Chemosphere, 162: 333-344. https://doi.org/10.1016/j.chemosphere. 2016.07.078

KASZA G., TEKLA IZSÓ T., CSENKI E.Z., MICSINAI A., NYIRO-FEKETE B., URBÁNYI B., ALPÁR B. (2020) Assessment of Dietary Exposure and Risk of DDT Concerning Freshwater Fish Aquaculture. Applied Sciences, 10:9083. https://doi.org/i:10.3390/app102490 83

KIZIEWICZ B., CZECZUGA B. (2003) DDT and Its Metabolites in the Tissues of Certain Fish Species from Podlasie Province. Polish Journal of Environmental Studies, 12(1):123 – 127.

KOEPKE R., WARNER M., PETREAS M., CABRIA A., DANIS R., HERNANDEZ-AVILA M., ESKENAZI B. (2004) Serum DDT and DDE levels in pregnant women of Chiapas, Mexico. Archives of Environmental Health, 59(11):559–565. https://doi.org/10.1080/00039890409603434

MABIKA N., BARSON M., VAN DYK C., AVENANT-OLDEWAGE A. (2019) Seasonal occurrence of metazoan parasites in Tigerfish, Hydrocynus vittatus Castelnau, 1861 (Characiformes: Alestidae) from Sanyati Basin, Lake Kariba, Zimbabwe. The Onderstepoort journal of veterinary research. 86:a1659. https://doi.org/10.4102/ojvr.v86i1.1659.

MAHUGIJA J.A.M., LUTAMYO NAMBELA L., MMOCH A.J. (2018) Determination of Dichlorodipheny ltrichloroethane (DDT) and Metabolites Residues in Fish Species from Eastern Lake Tanganyika. South African Journal of Chemistry, 71: 86–93. http://doi.org/10.17159/0379-4350/2018/v71a11

MANJENGWA, F., NHIWATIWA, T., NYAKUDYA, E., & BANDA, P. (2019) Fish from a polluted lake (Lake Chivero, Zimbabwe): a food safety issue of concern, Food Quality and Safety, 3(3):157–167. https://doi.org/10.1093/fqsafe/fyz015

MARUZIVA, R. (2016) Visualization of Temporal Aspects of Tsetse Fly Eradication in Zimbabwe on the Web. Ethiopian Journal of Environmental Studies and Management, 9:951-966. http://dx.doi.org/10.4314/ejesm.v9i2.2S

MBEWE, G., MUTONDO, M., MASEKA, K., AND SICHILONGO, K. (2016) Assessment of Heavy-Metal Pollution in Sediments and Tilapia Fish Species in Kafue River of Zambia. Archives of Environmental Contamination and Toxicology, 71(3):383-393. http://dx.doi.org/10.1007/s00244-016-0295-3

MBONGWE B. (2000) Fate and Persistence of DDT and Its Metabolites in the Okavango Delta, Botswana (Order No. MQ67838). Available from ProQuest One Academic. (304668520).

McCARTON B., MHLANGA W. (2003) Fish. Chapter 7. In the book DDT in the Tropics. The Impact on Wildlife in Zimbabwe of Ground – Spraying for Tsetse Fly Control.

MENDEZ A., NG C.A., TORRES J.P., MACHADO BASTOS W., BOGDAL C., HUNGERBUEHLER K. (2016) Modelling the Dynamics of DDT in a Remote Tropical Floodplain: Indication sof Post-Ban Use? Environmental Science and Pollution Research International, 23(11): 10317-10334. http://dx.doi.org/10.1007/s11356-015-5641-x

MHLANGA A.T., MADZIVA T.J. (1990) Pesticide Residues in Lake Mcllwane Zimbabwe. Ambio 19 (8): 368-372.

MHLANGA W. (2000) An Assessment of the Fish Population of the lower reaches of the Sanyati River, Zimbabwe. Southern African Journal of Aquatic Sciences, 25(1):84-88.

DOI: 10.6092/issn.2281-4485/18393

MOYO N.A.G. (1997) Lake Chivero: A Polluted Lake. University of Zimbabwe Publications, Conference Paper, pp. 134. ISBN 0908307608

NYGÅRD, T., SANDERCOCK, B. K., REINSBORG, T., AND EINVIK, K. (2019). Population Recovery of Peregrine Falcons in Central Norway in the 4 Decades since the DDT-Ban. Ecotoxicology, 28(10):1160-1168. http://dx.doi.org/10.1007/s10646-019-02111-4

OCHOA-RIVERO J.M., REYES-FIERRO A.V., PERALTA-PÉREZ M.D.R., ZAVALA-DÍAZ DE LA SERNA F.J., BALLINAS-CASARRUBIAS L., SALME-RÓN I., RUBIO-ARIAS H., ROCHA-GUTIÉRREZ B.A. (2017) Levels and Distribution of Pollutants in the Waters of an Aquatic Ecosystem in Northern Mexico. International Journal of Environmental Research and Public Health,14(5):456.https://doi.org/10.3390/ijerph14050456

OUMA K.O., SHANE A., SYAMPUNGANI S. (2022) Aquatic Ecological Risk of Heavy-Metal Pollution Associated with Degraded Mining Landscapes of the Southern Africa River Basins: A Review. Minerals, 12(2): 225. https://doi.org/10.3390/min12020225

PEDERCINI M., BLANCO S.M., KOPAINSKY B. (2011) Application of the Malaria Management Model to the Analysis of Costs and Benefits of DDT versus Non-DDT Malaria Control. PLoS One, 6(11) http://dx.doi.org/10.1371/journal.pone.0027771

RAO P.N. (2007) Resurrection of DDT. Indian Journal of Medical Research, 126(6):583.

RAYAISSE J.B., ESTERHUIZEN J., TIRADOS I., KABA D., SALOU E., DIARRASSOUBA A., SOLANO P. (2011) Towards An Optimal Design of Target for Tsetse Control: Comparisons of Novel Targets for the Control of Palpalis Group Tsetse in West Africa. PLoS Neglected Tropical Diseases, 5(9):e1332. http://doi.org/10.1371/journal.pntd.0001332

RITTER R., SCHERINGER M., MACLEOD M., HUNGERBÜHLER K. (2011) Assessment of Non-Occupational Exposure to DDT in the Tropics and the North: Relevance of Uptake via Inhalation from Indoor Residual Spraying. Environmental Health Perspectives, 119(5):707-12.

SADASIVAIAH S., TOZAN Y., BREMAN J.G. (2007) Dichlorodiphenyltrichloroethane (DDT) for Indoor Residual Spraying in Africa: How Can It Be Used for Malaria Control? In: Breman J.G., Alilio M.S-, White N.J, editors. Defining and Defeating the Intolerable Burden of Malaria III: Progress and Perspectives: Supplement to Volume 77(6) of American Journal of Tropical Medicine and Hygiene. Northbrook (IL): American Society of Tropical Medicine and Hygiene; 2007 Dec. Available from: https://www.ncbi.nlm.nih.gov/books/NBK1724/

SELOUS F.C. (2011) Travel and Adventure in South-East Africa. New York: Cambridge University Press. p. 445. ISBN 978-1108031165.

SHI, L. L., SHAN, Z. J., KONG, D. Y., AND CAI, D. J. (2006) The Health and Ecological Impacts of Organochlorine Pesticide Pollution in China: Bioaccumulation of Organochlorine Pesticides in Human and Fish Fats. Human and Ecological Risk Assessment, 12(2):402-407.

SIBALI, L. L., OKONKWO, J. O., AND ZVINOWANDA, C. (2009) Determination of DDT and Metabolites in Surface Water and Sediment using LLE, SPE, ACE and SE. Bulletin of Environmental Contamination and Toxicology, 83(6):885-91. http://doi.org/10.1007/s00128-009-9851-0

SOKO W., CHIMBARI M.J., MUKARATIRWA S. (2015) Insecticide Resistance in Malaria-Transmitting Mosquitoes in Zimbabwe: A Review. Infectious diseases of poverty, 4(1):1-12 http://dx.doi.org/10.1186/s40249-015-0076-7

VAN DEN BERG H. (2009) Global Status of DDT and Its Alternatives for Use in Vector Control to Prevent Disease. Environmental Health Perspectives, 117(11): 1656-63.

VAN DEN BERG H., MANUWEERA G., KONRADSEN F. (2017) Global Trends in the Production and Use of DDT for Control of Malaria and Other Vector-Borne Diseases. Malaria Journal, 16:1. http://doi.org/10.1186/s12936-017-2050-2

WANDIGA S.O. (2001) Use and Distribution of Organochlorine Pesticides. The Future in Africa. Pure and Applied Chemistry. Chimie Pure Et Appliquee, 73(7): 1147-1155. http://dx.doi.org/10.1351/pac200173071147

ZIKANKUBA V.L., MWANYIKA G., NTWENYA J.E., ARMACHIUS J. (2019) Pesticide Regulations and their Malpractice Implications on Food and Environment Safety. Cogent Food & Agriculture, 5(1) http://doi.org/10.1080/23311932.2019.1601544