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DDT water contamination and the impact on water quality access in Africa in relation to human health risks

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MKGLET006

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Part 0: Preamble

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Declaration:

I, Lethabo Makgoba, hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, or is to be submitted for another degree in this or any other university.

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Abstract:

DDT usage is prohibited in developed nations but exempted for use in indoor residual spraying (IRS) in developing countries, including African countries. No previous review of DDT residues in water resources has been conducted before in Africa. The study aimed to provide a review of available research investigating the levels of DDT residues in water sources in Africa and to assess the consequent human health risks. A scoping review of published studies conducted in Africa was facilitated through an extensive electronic search using PubMed, Web of Science, EBSCO HOST, and Scopus. A total of 20 articles were reviewed. The DDT concentrations varied between no detection to 81.2 µg/l, with 35% of the studies having found DDT concentrations that exceeded the WHO drinking water guideline of 1 µg/l, in the sampled water sources. South Africa (81.2 µg/l) and Egypt (5.62 µg/l) had the highest DDT concentrations in the sampled water sources. DDT levels were found to be higher during the wet season. Moreover, water from taps, rivers, reservoirs, estuaries, wells, and boreholes containing DDT residues was used to provide drinking water. Five studies conducted health risk assessments, and two studies found cancer risk values that exceeded the permissible limits in water sampled from sources that were used as a source of drinking water. Contrastingly, the non-carcinogenic risk values in the studies were below a hazard quotient of 1. DDT residues were detected throughout the year in African water systems. In conclusion, evidence of risks to human health was found as the concentration of DDT residues exceeded the WHO drinking water guidelines and/or cancer risk permissible limits in sampled drinking sources in African water systems. Alternative methods for malaria vector control should be investigated. Larger studies that include risk assessments and seasonal monitoring of DDT residues in multiple water sources are recommended.

Keywords:

Dichlorodiphenyltrichloroethane (DDT), risk assessment, water contamination, water sources, drinking water, Africa

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Acronyms & Abbreviations:

- DDT- Dichlorodiphenyltrichloroethane
- DDE- Dichlorodiphenyldichloroethylene
- DDD- Dichlorodiphenyldichloroethane
- IRS- Indoor Residual Spraying
- POPs- Persistent Organic Pollutants
- OCPs- Organochlorine Pesticides
- HQ- Hazard Quotient

Part A: Protocol

1. Introduction

1.1 What is DDT

Dichlorodiphenyltrichloroethane (DDT) is a synthetic organic man-made insecticide first synthesized in 1874 (Harada et al., 2016). At the end of the 1930s, its insecticidal effects were found, as it became widely used as an agricultural pesticide and a vector control for human health (US EPA, 2017). DDT is comprised of three types of organic compounds: 80% of DDT, 15% of o, p'-DDT, and 5% of o, o-DDT. These are white crystalline, odourless, solid substances (Nwabuibe, 2014).

Dichlorodiphenyltrichloroethane was originally used effectively to combat malaria and other insect-borne human illnesses in both civilian and military populations (US EPA, 2017). Additionally, it has been utilized in residential dwellings and gardens and has also been employed to control insects in agricultural and livestock production (US EPA, 2017). Even though DDT is no longer used in many regions, it is still utilized in a few developing nations, particularly in Africa, to reduce malaria-carrying mosquitoes (Nwabuibe, 2014).

1.2 Uses of DDT and its significance in Africa

Dichlorodiphenyltrichloroethane has been an effective intervention in eliminating the species of mosquito causing malaria in many countries and, thereby, decreasing the burden of malaria (Maharaj et al., 2005). Seasonal malaria epidemics caused many deaths in the 1930s and 1940s globally until the introduction of effective methods of vector control and antimalarial medicines. As a result of a variety of interventions, including extensive Indoor Residual Spraying (IRS) and the use of DDT, there has been a substantial and persistent decline in malaria case notifications, with the World Health Organization (WHO) reporting a decrease of 18% and 28% of malaria cases and deaths, respectively, from 2010 to 2017 (World Malaria Report, 2018).

Additionally, in the African Region, the case occurrence rate as reported by the WHO also decreased from 294 in 2010 to 229 in 2018, marking a 22% decrease, while other areas either made no improvements or saw a rise in the incident rate (World Malaria Report, 2019).

Due to DDT's persistence in the environment, its adverse effects on wildlife and its potential adverse effects on human health and consequent increasing pressure from environmental groups to stop its utilization, DDT was phased out in most developed regions for agricultural use in 1976 (US EPA, 2017), and for malaria control in 1996 (US EPA, 2017; Maharaj et al., 2005). To end the use of all persistent organic pollutants (POPs) including DDT, 152 nations approved and signed the Stockholm Convention on POPs in 2001 (Channa et al., 2011), but countries that still relied on DDT as a less costly method for controlling malaria were exempted. In September 2006, the WHO approved the use of IRS with DDT in African nations where malaria remains a severe health burden, outlining that DDT's benefits outweigh the environmental and human health risks, as a cost-effective method to control malaria (WHO, 2006).

Indoor residual spraying is the practice of applying pesticide to home interiors in order to eradicate malaria-carrying insects (Pisa and Bouwman, 2020). In areas of Africa where DDT is used, it is applied inside houses on the walls and roofs (Barnhoorn et al., 2009). It works in such a way that if a mosquito rests on a sprayed wall, the insecticide particles are sucked in by the mosquito, which eventually dies (Mishra et al., 2021). Indoor residual spraying was the main malaria prevention intervention during the early 20th century, achieving a drastic decline in malaria (Pisa and Bouwman, 2020). In malaria endemic regions, the introduction of IRS was particularly impactful immediately after its implementation (Mabaso et al., 2004). Other control initiatives, such as drug prophylaxis attempts, larvicide, and environmental sanitation, were typically attempted prior to IRS in most countries, but with minimal results (Mabaso et al., 2004). From the 1940s and 1960s, IRS, mainly by DDT, was the primary strategy that substantially decreased malaria in many countries around the world (Mabaso et al., 2004). In support of this, early malarial eradication pilot projects in sub-Saharan Africa demonstrated that malaria is extremely susceptible to IRS DDT vector control (Mabaso et al., 2004).

Dichlorodiphenyltrichloroethane is strongly lipophilic and survives for a long time in the environment, along with its breakdown product, dichlorodiphenyldichloroethylene (DDE) (Pisa and Bouwman, 2020). Once released, DDT can stay for up to 15 years in the environment or degrade into its primary metabolites, namely

dichlorodiphenyldichloroethane (DDD) and DDE. Of these, DDT is the most persistent (Barnhoorn et al., 2009), and it has a half-life of about 11 years (Sadasivaiah et al., 2007). Consequently, residents living in areas where IRS is performed are at risk of being susceptible to excessive levels of DDE and DDT. Physical contact, inhalation of indoor sprays, and ingestion of contaminated water and food are the main modes of exposure. In its dissolved or particulate remnant form, DDT may enter surface water sources, which can affect the quality of water, jeopardize aquatic life and is a source of exposure to humans via recreational and drinking resources (Asi et al., 2008). As a result, there is growing concern about DDT's effects on the health of humans and the environment (Aneck-Hahn et al., 2007; Mansouri et al., 2016).

1.3 DDT impacts on water quality

Dichlorodiphenyltrichloroethane spraying can pollute bodies of water globally as a nonpoint source of waste, contaminating the drinking water supply (Kurakalva and Aradhi, 2020). This is especially true in nations that manufacture DDT, such as India, China, and Korea (Van den Berg, 2009). Additionally, DDT pollution also affects countries that have and still use DDT, such as South Africa, Mozambique, Ethiopia, Sudan, Zambia, and Zimbabwe, which are all African countries (Van den Berg, 2009). Data from India, Brazil, South Africa, and Mexico suggests that DDT levels in soil or water samples are greater in regions where DDT residual spraying occurs as opposed to areas without spraying (Van den Berg, 2009).

Even though the manufacturing and utilization of organochlorine pesticides (OCPs) has been prohibited, there is growing concern about their longevity, toxicity, biomagnification, and bioaccumulation in the environment (Bouwman et al., 2012; Jin et al., 2014). DDT has been found to be more persistent than other chlorinated pesticides (Saadati et al., 2012). DDT is liposoluble and, as a result of its lipophilicity, it can be absorbed quickly in the intestinal tract and reach the circulatory system of humans and animals. This substance has been found in the fatty tissues of humans, including blood, hair, adipose tissues, muscles, and breast milk (Chavez-Almazan et al., 2014). Hence, adverse health effects have been linked to exposure to this persistent chemical (Ahmed et al., 2015).

Organochlorine pesticides reach water sources via several pathways, including drainage pollution from agricultural areas where pesticides are used, pesticide dust or droplets during application processes like IRS, pesticide containers and from cleaning agricultural machinery (Liu et al., 2013). Freshwater contamination is a major concern worldwide because land waters are contaminated with chemical pollutants from mines and other manufacturing operations, as well as pesticides from crop runoff (UNEP, 2008).

Pilot experiments in the Limpopo Province, South Africa, investigating environmental pollution with DDT have raised questions about water quality and estrogenic activity in water bodies where DDT spraying takes place. Animals which could be used as pollution indicators were tested, and the results indicated that chickens, two fish species, land and sea birds were all contaminated (Barnhoorn et al., 2009). Additionally, another pilot analysis done in northern South Africa observed large amounts of DDT and metabolites in numerous aquatic and terrestrial biota in a DDT-sprayed area (Bornman et al., 2009).

Hence, investigating the presence of DDT in waterbodies is crucial, especially in light of its potential negative impacts on human health. As the above-mentioned studies indicate, DDT has been found in animals, indicating that humans are also exposed to it. Safe drinking water is critical for long-term human health, socioeconomic progress, and standard of living, and it is required for developing nations to fulfil the Sustainable Development Goal (SDG) of having access to adequate sanitation and clean water by the year 2030 (Saeedif et al., 2015). The presence of pesticides such as DDT, on the other hand, even at low concentrations, in water sources, especially those used for drinking, can compromise human health and water quality (Affum et al., 2018). The WHO (2017) has set a guideline value of 1 µg/l for DDT in drinking water.

1.4 Long-term health implications related to DDT

Dichlorodiphenyltrichloroethane utilization remains a topic of attention, mainly due to its effect on humans and because of its historical and continual use in malaria control (Eskenazi et al., 2009; Bouwman et al., 2011). Concerns about the continued utilization of DDT arise mostly due to its toxicity, bioaccumulation, and persistence

(Bouwman et al., 2012; Jin et al., 2014). The number of research and analyses that have concentrated on DDT and its impact on human health has risen during the past ten years (Cohn et al., 2015; Bornman et al., 2018; Gerber et al., 2016; Eskenazi et al., 2009).

An increasing amount of research suggests that DDT exposure may have negative effects on human health (Eskenazi et al., 2009; Ritter et al., 2011). Existing epidemiological data shows that DDT's biological activity on human biological systems has several health implications, such as endocrine disruption leading to adverse impacts on the female and male reproductive systems, influencing neurological development and behavior. Furthermore, negative immunological effects, asthma, cancer, effects on child development and growth (Bouwman et al., 2011), and internal organ and skin disorders (Poursaberi et al., 2012) are all possible. DDT is also linked to an increased risk of chronic illnesses, such as hypertension, diabetes, and heart disease (Carpenter, 2011).

Among men exposed to DDT, there are reports that it can cause testicular cancer (Eskenazi et al., 2009) and decrease semen quality (Bouwman et al., 2011; Dalvie et al., 2004). Similarly, other investigations conducted in endemic regions in Mexico and Limpopo Province (South Africa) have shown that DDT exposure has been linked to poor sperm quality (Bonde, 2010; Dalvie et al., 2004). In females, DDT exposure has been associated with spontaneous abortion in pregnancy and developing breast cancer in adulthood, especially with pre-puberty exposure (Bouwman et al., 2011).

Children are uniquely vulnerable to the negative health consequences of DDT due to their dietary, developmental, and physiologic factors (Roberts et al., 2012). They are most vulnerable to exposure during their embryonic and fetal stages (Channa et al., 2011) in relation to physical and mental development (Roberts et al., 2012; Eskenazi et al., 2009). According to reports, in utero DDT exposure can have a negative effect on neurodevelopment in children, resulting in delayed psychomotor development, behavioral problems, and decreased cognitive function (Channa et al., 2011). Recent South African research has linked DDT exposure to urogenital abnormalities in newborn males as well as reduced semen quality (Roberts et al., 2012). Various evidence shows that in children, a high blood DDT concentration may have an

impact on the body mass index and other growth indicators (Channa et al., 2011; Eskenazi et al., 2009).

2. Rationale

Chemical pollution of water sources, such as rivers, has long been a cause of concern across the world, as well as a persistent challenge in developing nations. Contributing causes include modern phenomena such as population density, urbanization, and increased human activity (Unyimadu et al., 2018). Continuous monitoring of chemical contaminants in water bodies in developed nations has served as a foundation for policy formation and pollution management with the aim of achieving clean water bodies. Among the numerous POPs, OCPs have a long history of usage in Africa, and it has been noted that they are present in food and water (Unyimadu et al., 2018). As a result, there is a need for regional evaluation of hazardous chemicals, notably POPs, in water bodies, particularly in Africa (Unyimadu et al., 2018).

Dichlorodiphenyltrichloroethane is one of the major OCPs known to be very toxic because of their persistence, long biological half-life, and high lipophilicity (Wan et al., 2005). Water bodies, as an essential environmental medium, contribute significantly to the migration and transformation of OCPs such as DDT. Agricultural nonpoint source contamination, atmospheric sedimentation, and industrial wastewater discharge are some of the contributors to OCPs entering rivers and lakes. Even though most OCPs are highly insoluble in water, organisms quickly absorb them and they can bioaccumulate in the food chain, thereby causing health hazards (Liu et al., 2020). Although DDT is credited for successfully controlling malaria in certain nations (Eskenazi et al., 2009), the possible impact on human health and exposure risks to DDT contaminated water or other indirect water-related exposures should be considered. As a result, it is critical to evaluate levels of DDT pollution in possible environmental pathways, especially water sources, in relation to human exposure (Van Dyk et al., 2010).

No previous reviews have been carried out specifically investigating DDT contamination in water sources in Africa, but they have been conducted in other countries outside of Africa. Two reviews done in China found that DDT levels were

high enough in seafood samples to have negative effects on human health (Zhang et al., 2013), and that DDT was the most relevant matrix for assessing environmental risk in aquatic organisms (Grung et al., 2015). Additionally, a review conducted in South America found that DDT was more prevalent than other OCPs for all environmental matrices (Girones et al., 2020). Since such reviews are scarce in Africa, the goal of this study is to find out what evidence of DDT contamination in water sources exists and whether this contamination poses health risks to humans exposed to DDT contaminated water. This study could aid in the promotion of more research on the impact of DDT on water quality, particularly in many African countries, where DDT is still widely used. It can also be used to inform policy, because even though DDT is a low-cost and cost-effective antimalarial chemical, the environmental and human health risks from IRS exposure must be carefully considered against the benefits of malaria prevention.

3. Aim & Objectives

3.1 Aim

The aim of the study is to conduct a scoping review of available research that has investigated the levels of DDT in water sources in Africa and to assess the human health risks due to DDT exposure from water contamination.

3.2 Objectives

- To systematically assess available research on the presence and concentrations of DDT in water sources.
- To evaluate the types of water sources in which DDT residues are prevalent.
- To summarize the available research on the human health risks associated with DDT contaminated water resources.

4. Methods

For this review, the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocol (PRISMA-P) guidelines (Shamseer et al., 2015; Moher et al., 2015) will be used.

4.1 Search strategy

The following databases will be used to perform a comprehensive electronic literature search:

- PubMed (Medline)
- Web of Science (WOS, BIOABS, KJD, RSCI, SCIELO)
- EBSCO HOST (Cinahl, Cinahl Complete, Biological and Agricultural Index, Africa-wide, Environment complete, Academic search ultimate)
- Scopus

The systematic search will be done by combining possible combinations of keywords and free text words. In addition to this, Medical Subject Heading (MeSH) terms will also be included when searching in PubMed (Medline). As relevant studies are identified, other studies that are possibly relevant will be obtained from reference lists and citation indexes of the initial studies found in the search. All relevant published studies will be used to create summaries and overviews of quantitative evidence investigating the presence of DDT in waterways and human health assessments in relation to DDT exposure.

4.2 Data Collection and Analysis

4.2.1 Study selection

Search results will be exported to Endnote. For the first phase of screening, the primary investigator will determine whether the publications meet the requirements for inclusion or exclusion by screening the titles and abstracts of articles. If it is unclear whether an article is eligible from the title or abstract, the full text will be read, and if it is still not clear at this stage, the study supervisors will then be approached for guidance.

4.2.2 Data extraction and management

Data will be extracted from the selected articles and organised into summary tables. The table variables will include the authors' name and publication year; study setting/location; number of sampling sites and size; sampling period and season;

type of water medium; water contamination sources; DDT levels in water sources; and a summary of human health risk assessments.

4.2.3 Assessment of risks and bias

Individual studies may not be subjected to formal risk and bias assessments, but they may be reviewed using the Critical Appraisal Skills Programme (CASP) checklist/criteria (CASP, 2018) for evident flaws and bias.

4.3 Inclusion criteria

A study will be deemed eligible if it meets the following inclusion criteria:

- Studies published in English;
- Studies done in African countries;
- Studies that report the presence or levels of DDT in water sources;
- Studies published from 2010 to June 2021 (Recent studies will be able to reflect on the most current or recent DDT levels in water sources, and because DDT is said to be persistent, recent studies will be able to reflect on its long-term effects. Additionally, most studies that align with the aim of this study, which is focused on DDT in water environments, are studies from 2010).

4.4 Exclusion criteria

A study will not be deemed eligible if it meets the following exclusion criteria:

- Studies published in other languages besides English;
- Studies with missing or incomplete data;
- Studies focusing on DDT exposure of animals, especially aquatic animals which have no direct link to adverse health effects of humans and their exposure;
- Studies where DDT levels were measured using other samples besides water samples.

5. Ethics

This is a scoping review and therefore a desktop activity, hence no ethical approval is required and only studies with institutional ethical approval will be included in the study. The protocol will be submitted to the Departmental Research Committee of the School of Public Health and Family Medicine at the University of Cape Town (UCT) and passed down to the Faculty of Health Sciences Research Ethics Committee at the University of Cape Town for approval (see Appendix A).

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Part B: Article

Article to be submitted to the Science of The Total Environment journal and is written in accordance with the instructions for authors by the journal.

1. INTRODUCTION

The utilization of the insecticide, dichlorodiphenyltrichloroethane (DDT), has been a major public health concern globally, because of its toxicity and longevity in the environment since the 1960s. Although DDT has been banned in the majority of countries for decades, traces have been found in water, aquatic biota, and sediments all over the world (Wang et al., 2013). Some countries in Asia, South America, and Africa still use DDT for mosquito control to reduce the risk of malaria (Kimutali, 2017).

Dichlorodiphenyltrichloroethane is generally broken down into highly persistent metabolites (Dichlorodiphenyldichloroethylene (DDE) and Dichlorodiphenyldichloroethane (DDD)) once it reaches the environment. DDT and its metabolites typically enter the environment through sediments, particularly those in lakes and wetlands. These contaminants build up in benthic animals and can move up the food chain at higher trophic levels (Humphries, 2013).

A South Asian review article (Sarker et al., 2021) which included studies undertaken in India, Pakistan, Nepal, and Bangladesh, reviewed the extent of pesticide pollution in these countries' major river systems, with DDT and its metabolites as one of the pesticides being evaluated. Six rivers and a lake were evaluated for DDT and other pesticides, and two rivers from India (Chilika Lake and Tapi River) had concentrations greater than the WHO guideline value of 1 µg/l, with the highest concentration being 23.58 µg/l detected in the Chilika lake (Sarker et al., 2021).

A South China review conducted in different environments of the Pearl River Delta (Zhang et al., 2013) also examined the levels and distribution patterns of a number of persistent organic pollutants (POPs), including DDT. A total of 13 surface water resources were evaluated across 8 studies, and all of the DDT levels found in the water resources were below the WHO drinking water guideline threshold of 1 µg/l. The highest DDT level found was 0.2 µg/l in Shenzhen River in 1994 and lowest level was 0.0004 µg/l in Pearl River Delta in 2009, the results indicate that in South China, DDT levels appeared to have gradually decreased over the years (Zhang et al., 2013).

Moreover, another review study conducted in South America by Girones et al., (2020), that examined OCP concentrations in fish, marine animals, soil, water, and the air along the coastlines of South America and sea surface waters between 1998 and 2019, found that in comparison to other OCPs, DDT and its breakdown products were more prevalent in all environmental matrices (Girones et al., 2020). Two of the studies analysed the OCP levels in Colombia's coastal waters. The first one analysed OCPs in unfiltered water, and DDT was found in 25% of the samples. Additionally, the second study analysed DDT levels in sea water, with DDT being the most prevalent pesticide with a 95% detection rate at the chosen sites (Menzies et al., 2013), and the highest concentration of DDT found in this review was 0.1 µg/l in Santa Marta Bay (Girones et al., 2020). The reviews mentioned above evaluated studies that measured DDT levels in rivers, lakes and the sea and not directly in drinking water, but some of the water sources like the rivers and lakes provided treated drinking water.

Unlike other continents, a review has not been done in Africa, specifically focusing on DDT levels and contamination in water sources, although DDT is still utilized in a number of countries, such as Ethiopia, Swaziland, Uganda and South Africa (Kimutali, 2017). Hence, this study aims to (1) provide a review of available recent research, published between 2010 and June 2021, exploring the levels of DDT in water sources in Africa and (2) to assess the human health risks due to DDT exposure from water contamination.

2. METHODS

2.1 Study Design

A scoping review of original studies published in peer-reviewed journals between 2010 and 2021 was conducted to determine the contamination levels of DDT in water sources and risks posed to human health.

2.2 Literature Search Strategy

An extensive electronic search was conducted using PubMed, Web of Science, EBSCO HOST, and Scopus. The search strategy included keywords related to DDT

AND water contamination AND human health risk. The search was limited to articles written in English and published between 2010 and June 2021; studies from 2010 were chosen as recent studies will be able to reflect on the most current or recent DDT levels in water sources. Appendix B details the search terms used for each database.

2.3 Selection of studies

This review followed the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocol (PRISMA-P) guidelines (Appendix C). An eligibility criterion was developed before the study was conducted to help determine the publications that would be part of the review. The primary investigator reviewed the articles, and another reviewer was consulted in situations of doubt about inclusion, and after a thorough discussion, consensus was reached.

A study was deemed eligible if it met the following inclusion criteria:

- Studies published in English;
- Studies done in Africa;
- Studies that report the presence/ levels of DDT in water sources; and
- Studies published from 2010 until June 2021.

A study was not deemed eligible if it met the following exclusion criteria:

- Studies published in other languages besides English;
- Studies with missing or incomplete data;
- Studies focusing on DDT exposure of animals especially aquatic animals which have no direct link to adverse health effects of humans and exposure; and
- Studies where DDT levels were measured using samples other than water samples.

3. RESULTS

The initial search identified a total of 80 articles using 4 databases (Figure 1). After removing duplicates, 70 articles were screened by their titles and abstracts. After this first phase of screening, 43 articles were excluded, and the remaining 27 underwent full-text screening. Seven further articles were excluded after full-text screening, leaving 20 eligible articles for review (See Figure 1 and Appendix C). The 20 eligible studies were categorised by location in ten African countries, including: South Africa (5), Nigeria (3), Ghana (2), Kenya (2), Mozambique (1), Ethiopia (1), Zambia (1), Tanzania (1), Egypt (2), and Morocco (2).

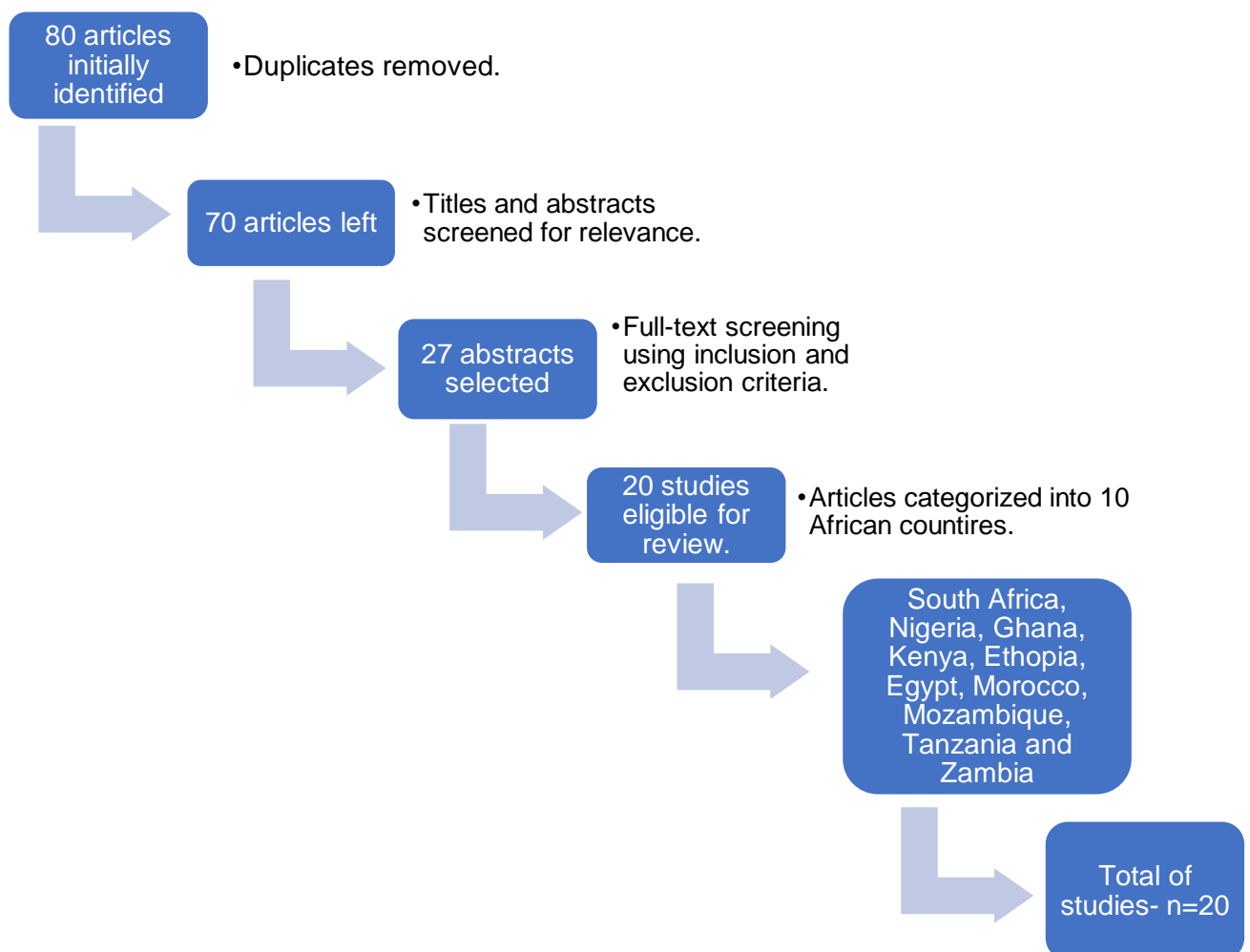


Figure 1: Steps followed in the literature search

3.1 DDT residue levels in Southern Africa's waterways

Table 1: Studies reporting DDT levels in Southern African water resources

No	References	Location & Country	No of Sampling sites & size	Sampling period and season.	Water Media	Contamination of water sources	Uses of water media.	DDT levels ($\mu\text{g/l}$)	Summary of human health risk assessment.
1	(Olisah et al. 2019)	Eastern Cape, South Africa	5 sites, 400 samples	Oct 2017 - Sept 2018. (All seasons).	Surface water; Sundays (SDE) & Swartkops Estuaries (SWE)	Discharge of various solid & industrial pollutants, no known recent DDT applications.	Agricultural and domestic use (drinking & bathing)	Mean Σ DDT Wet season= 0.02; Pre-dry season= 0.05 Dry season= 0.02 Pre-Wet season= 0.01	Risk assessment ratio in SDE 2.54×10^{-7} (drinking water), and 1.10×10^{-9} (bathing water) for carcinogenic risk. 3.38×10^{-3} (drinking water), and 1.47×10^{-5} (bathing water) for non-carcinogenic risk. Risk assessment ratio in SWE 6.63×10^{-7} (drinking water) and 2.89×10^{-9} (bathing water) for carcinogenic risk. 8.84×10^{-3} (drinking water) and 3.85×10^{-5} (bathing water) for non-carcinogenic risk.
2	(Adeyinka et al. 2019)	KwaZulu Natal, South Africa.	9 sites	16 – 17 July (dry season) and 25-26 Sept 2013 (pre-wet season).	Surface water (Msunduzi river)	Various anthropogenic activities, no known recent DDT applications.	Major source of water for the area.	p.p-DDT = 19.95 (dry season) p.p-DDD = 81.15 (pre-wet season)	N/A
3	(Yahaya et al. 2017)	Eastern Cape, South Africa.	6 sites	Dec 2015 (wet season) – May 2016 (dry season)	Surface water (Buffalo river)	Various household & industrial pollutants, no known recent DDT applications.	Domestic & Agricultural purposes.	Σ DDT Wet season = 1.43 Dry season= 0.45	Non- cancer risk: Hazard Quotient (HQ) for different age groups 4,4-DDE: ($14,751 \times 10^{-6}$), (8741×10^{-6}) and (2950×10^{-6}) for age groups 0-6, 7-17 and adults, respectively.

									4,4-DDD: (8306x10 ⁻⁶), (4922x10 ⁻⁶) and (1661x10 ⁻⁶) for age groups 0-6, 7-17 and adults, respectively. 4,4-DDT: (12x10 ⁻⁶), (7x10 ⁻⁶) and (2x10 ⁻⁶) for age groups 0-6, 7-17 and adults, respectively.
4	(Van Dyk et al. 2010)	Limpopo, South Africa	2 sites 12 samples	Feb 2008 (wet season)-summer	Tap water	IRS with DDT.	Used for drinking and other domestic purposes.	∑DDT = 7.6 (wet season)	N/A
5	(Barnhoorn et al. 2010)	Limpopo, South Africa.	3 sites	Not stated	Surface water (Luvuhu river)	IRS with DDT.	–	∑DDT Survey 1= 0.12 Survey 2= 0.7 Survey 3= 2.3 Survey 4= 2.2	N/A

Among Southern African countries (Table 1), only studies from South Africa were found. Five studies were carried out in South Africa; two in the Eastern Cape (Olisah et al., 2019, Yahaya et al., 2017), two in Limpopo (Van Dyk et al., 2010, Barnhoorn et al., 2010) and one in Kwa-Zulu Natal (Adeyinka et al., 2019). Four studies (Olisah et al., 2019; Yahaya et al., 2017; Barnhoorn et al., 2010; Adeyinka et al., 2019) detected DDT residues in surface water (from 4 rivers and one estuary), and one study detected DDT residue in drinking water from taps (Van Dyk et al., 2010). DDT residues in the 5 studies were detected throughout the year but varied seasonally and peaked in different seasons in the different areas. The provinces in which the studies were conducted (Limpopo, Kwa-Zulu Natal and the Eastern Cape) have the same microclimates with rainy summers and dry winters.

The DDT concentrations in the majority of the sampling sites in studies by Adeyinka et al. (2019) (conducted during the wet and pre-wet seasons), Yahaya et al. (2017) (conducted in the wet season), Van Dyk et al. (2010) (conducted during the wet season), and Barnhoorn et al. (2010) (season not specified) exceeded the WHO drinking water guideline of 1 µg/l including samples from tap

water used for drinking (Van Dyk et al., 2010). The highest DDT concentration was detected at 81.15 µg/l in the Msunduzi River during the pre-wet season (Adeyinka et al., 2019).

Only the two studies in the Eastern Cape - Olisah et al. (2019), which was conducted throughout all seasons, and Yahaya et al. (2017), which was conducted during the dry and wet seasons - conducted a health risk assessment. In the study by Olisah et al. (2019), the risk hazard maximum value for DDTs in Sundays Estuaries was 2.54×10^{-7} in drinking water and 1.10×10^{-9} in bathing water for carcinogenic risk; 3.38×10^{-3} in drinking water, and 1.47×10^{-5} in bathing water for non-carcinogenic risk. On the other hand, in Swartkops Estuaries the maximum DDT residue levels were 6.63×10^{-7} in drinking water and 2.89×10^{-9} in bathing water for carcinogenic risk, and 8.84×10^{-3} in drinking water and 3.85×10^{-5} in bathing water for non-carcinogenic risk (Olisah et al.2019). Unlike the study by Olisah et al. (2019), the study by Yahaya et al. (2017) only evaluated the non-carcinogenic risk according to age groups. One in a million, or 1×10^{-6} , represents the acceptable lifetime cancer risk. A risk level between 1×10^{-6} and 1×10^{-4} is seen as concerning, while one above 10^{-4} is regarded as an unacceptable risk (US-EPA, 2005). In terms of the risk assessment outlined above, the cancer risk values found, are well within the permissible guidelines as they are lower than 1×10^{-6} . Additionally, humans may be exposed to non-carcinogenic effects when the Hazard Quotient (HQ) values are greater than one, but when they are less than one, it is unexpected for the exposed person to develop negative health effects (Mohammadi et al., 2019). Hence, in terms of the HQ values found in the above studies, the values are well within the permissible guideline as they are lower than one.

3.2 DDT residue levels in West Africa's waterways

Table 2: Studies reporting DDT levels in West African water resources

No	References	Location & Country	No of Sampling sites & size	Sampling period and season.	Water Media	Contamination of water sources.	Uses of water media.	DDT levels (µg/l)	Summary of human health risk assessment.
Nigeria									
1	(Ogbeide et al. 2015 ^a)	Edo State, Nigeria	72 Samples	Jan 2012 to June 2013 (Covered all the seasons).	Surface water (Owan river)	Flow of agrochemicals from cocoa plantations, no known recent DDT applications.	Agricultural use	Mean DDT= 0.12 (all seasons)	N/A
2	(Ogbeide et al. 2015 ^b)	Edo State, Nigeria	216 Samples	Jan 2012 to June 2013 (Covered all the seasons)	Surface water (Illushi river)	Acts as a drainage system for the area's rice fields, no known recent DDT applications.	Used for drinking & domestic purposes.	Mean DDT= 0.09 (all seasons)	Non-cancer risk: HQ= 0.0158 (Children) HQ= 0.0046 (Adults)
3	(Olutona et al. 2014)	Iwo, Nigeria	1 site	Nov – Dec 2012 (dry season-winter)	Surface water (Aiba man-made reservoir)	Contamination from fishing, farming, cleansing of household goods and autos, no known recent DDT applications.	Used to preserve drinking water.	∑DDT= 0.12 (dry season)	N/A
Ghana									
4	(Affum et al. 2018)	Western region of Ghana.	11 sites 88 Samples	Aug – Oct 2016 (wet)	Surface water (Ankobra basin, Peme)	Agricultural runoff from cocoa fields, no	Used for drinking purposes.	Surface water ∑DDT= 0.08 (wet season)	Cancer risk:

				season-summer)	river & streams) Ground water (boreholes)	known recent DDT applications.			p,p'-DDT= (infants: 5.1×10^{-6} to 1.28×10^{-5} ; children: 1.56×10^{-6} to 2.55×10^{-6}); p,p'-DDD = (infants: 1.8×10^{-5} ; children: 3.6×10^{-6}); p,p'-DDE (infants: 2.6×10^{-6} ; children: 2.6×10^{-6}) .
								Ground water Σ DDT= 0.06 (wet season)	Cancer risk: p,p'- DDT= (infants: 2.8×10^{-5} ; children: 1.5×10^{-6}) and (infants: 7.7×10^{-6} ; children: 5.6×10^{-6}).
5	(Fosu-Mensah et al. 2016)	Western Brong-Ahafo, Ghana.	4 sites 64 samples	Dec 2014- Feb 2015 (dry season-winter)	Hand dug wells	Runoff from cocoa farms, no known recent DDT applications.	Used for drinking and domestic purposes.	p.p'-DDT= 0.04 (dry season)	N/A

In West Africa, studies were conducted in Nigeria and Ghana (Table 2). Chronic insect infestations and epidemics in Nigeria resulted in pesticide spraying (Ogbeide et al., 2015^b). Three studies in Nigeria investigating DDT levels in surface water from two rivers and a reservoir were identified. A study by Olutona et al. (2014) was carried out during the dry season and had the lowest DDT concentrations (ranging from 0.03 µg/l to 0.05 µg/l). Higher DDT levels of 0.12 µg/l and 0.09 µg/l were found in the studies by Ogbeide et al. (2015^a) and Ogbeide et al. (2015^b), respectively, conducted throughout all the seasons. DDT levels in all of these studies were below the WHO drinking water guideline threshold of 1 µg/l, including the Aiba reservoir (Olutona et al., 2014) and Illushi River basin (Ogbeide et al., 2015^b), used for drinking. Only Ogbeide et al. (2015^b) conducted a human risk assessment and found no potential non-cancer effects as the HQs were lower than one.

Two studies by Affum et al. (2018) and Fosu-Mensah et al. (2016) were conducted in western Ghana to explore the levels of OPCs in surface and groundwater sources. Affum et al. (2018) found DDT levels of 0.08 µg/l and 0.06 µg/l during the wet season in water samples which were taken from both ground (boreholes) and surface water (rivers). In contrast, in the Fosu-Mensah et al. (2016) study, sampling of ground water took place during the dry season and a lower concentration of 0.04 µg/l was found. In both studies, the DDT concentrations did not vary much and were all below the WHO drinking water guideline threshold of 1 µg/l for drinking water. When assessing risk assessments, in the study by Affum et al. (2018), the cancer risk values found for children and infants were higher than the permissible guideline of (1×10^{-6}) based on the US-EPS standard (2005).

3.3 DDT residue levels in East Africa's waterways

Table 3: Studies reporting DDT levels in East African water resources

No	References	Location & Country	No of Sampling sites & size	Sampling period and season.	Water Media	Contamination of water sources.	Uses of water media.	DDT levels (µg/l)	Summary of human health risk assessment.
Kenya									
1	(Muendo et al. 2012)	Bungoma district, Kenya.	–	Aug 2008 (wet period) & Dec 2008 (light rain period)	Surface water (river kuywa)	Runoff from sugarcane farms, no known recent DDT applications.	Used for drinking purposes.	p.p'-DDT= 1.36 (wet season) p.p'-DDT= 0.17 (light rain season)	N/A
2	(Musa et al. 2011)	Victoria Basin, Kenya.	7 sites	Jan -March 2009 (dry season) Oct – Dec 2009(wet-light rain season)	Surface water (Nyando Sondu-Miriu Basin)	Contamination by agricultural pesticides & insecticides, no known recent DDT applications.	Source of water for residential, irrigation, industrial and power generation.	∑DDT = 0.36 (wet season) ∑DDT = 0.29 (wet-light rain season)	N/A
Mozambique									

3	(Villanueva et al. 2021)	Manhica district, Mozambique.	20 sites	July 19 th & 25 th 2018 (dry season)	Ground water (boreholes) Surface water (Wells & build fountains)	DDT runoff from IRS.	Serves as sources of drinking water.	\sum DDT= 0.03 (dry season)	N/A
Ethiopia									
4	(Loha et al. 2020)	Central rift valley, Ethiopia	12 sites	March, May & July 2015; July 2016.	Tap water and surface water (rivers)	DDT contamination through IRS.	Agricultural and drinking purposes.	Not detected.	N/A
Zambia									
5	(Munyinda et al. 2015)	Zambia	3 sites	July 2012 (dry season)	Surface water (shallow wells & open streams) & taps.	DDT contamination through IRS.	Sources of drinking water.	\sum DDT= 0.77 (dry season)	N/A
Tanzania									
6	(Hellar-Kihampa et al. 2013)	Tanzania	12 sites	Sept- Oct 2009 (dry season); March- April 2010 (rainy season); Jan-Feb 2011 (pre-rainy season).	Surface water (Pangani river & tributaries)	Agrochemical pollution linked to fast-growing floriculture. Small-scale farmers around the river basin cultivate a range of fruits and vegetables near to water sources, threatening river water quality. No known recent DDT applications.	Drinking and domestic uses, also used by cattle, hydropower generation & industries.	Max \sum DDT=0.002 (dry season)	N/A

In East Africa, studies were conducted in Kenya, Mozambique, Ethiopia, Zambia, and Tanzania (Table 3). In Kenya, two studies by Musa et al. (2011) and Muendo et al. (2012) were conducted during wet and wet-light rain seasons where water samples were

drawn from surface water in different rivers. In both studies, higher DDT concentrations were found during the wet season; a higher concentration of 1.36 µg/l, which slightly exceeds the WHO guideline, was measured in the study by Muendo et al. (2012), whereas in Musa et al. (2011), a concentration of 0.36 µg/l was measured during the wet season.

In evaluating Mozambican studies, it is important to consider that the economy of Mozambique largely depends on informal trading, small-scale family farming, and the sugar cane industry, which is heavily reliant on pesticides. In 2005, DDT spraying for malaria control was reinstated in Mozambique (Villanueva et al., 2021). One study assessed DDT levels in drinking water samples in Manhiça district collected during the dry season, and found a total DDT residue level of 0.03 µg/l, which was below the WHO drinking water guideline (Villanueva et al., 2021).

In order to stop the spread of malaria, DDT is still used in Ethiopia for IRS. Moreover, 80% of Ethiopia's population relies on farming as their main source of income, and local farmers still use DDT illegally (Loha et al., 2020; Lamoree and de Boer, 2020). Only one study investigating DDT levels in surface water samples from agriculture, effluents from floriculture and drinking water from taps was conducted, but no DDT residues were detected in any of the samples (Loha et al., 2020).

Moreover, in Zambia, a study investigating DDT levels in various samples, including drinking water, was conducted during the dry season in three regions, including a control region where no DDT spraying occurred (Munyinda et al., 2015). In the control region, DDT residues were not detected, but in regions where DDT was applied, the highest concentration of DDT found was 0.77 µg/l (Munyinda et al., 2015), which was below the WHO drinking water guideline for DDT.

Lastly, in Tanzania, a study investigated DDT levels in surface water used for drinking and recreational use (Hellar-Kihampa et al., 2013), throughout all seasons and detected DDT in 58% of water samples. The highest concentration found was 0.002 µg/l for total DDT during the dry season, which was below the WHO drinking water guideline for DDT.

3.4 DDT residue levels in North Africa's waterways

Table 4: Studies reporting DDT levels in North African water resources

No	References	Location & Country	No of Sampling sites & size	Sampling period and season.	Water Media	Contamination of water sources.	Uses of water media.	DDT levels (µg/l)	Summary of human health risk assessment.
Egypt									
1	(Dahshan et al. 2016)	Egypt	20 sites 60 samples	Summer 2013 (dry season)	Surface water (Nile river)	Sources of contamination not mentioned in the study and no known recent DDT applications.	Main source of drinking water.	∑DDT= 5.62 (dry season)	N/A
2	(Kamel et al. 2014)	Egypt	4 Sites	Oct 2012 (dry season) and March 2013 (wet seasons)	Surface water (Manzala lake)	Meeting place for a number of contaminated water supplies, no known recent DDT applications.	Recreational use (fishing)	p,p'-DDT= 3.23 (dry season) p,p'-DDT= 3.36 (wet season)	N/A
Morocco									
3	(Berni et al. 2021)	North-central Morocco	22 sites 84 Samples	Summer 2017 (dry season) Winter 2018 (wet season)	Ground water (wells)	Contamination from earlier use of technical DDT.	Utilized for drinking and agricultural purposes.	∑DDT = 0.06 (dry season) ∑DDT = 0.03 (wet season)	Carcinogenic risk values: DDT 1.8 x 10 ⁻⁵ (infants); 1.6 x 10 ⁻⁶ (children) & 2.4 x 10 ⁻⁷ (adults). DDE 1.8 x 10 ⁻⁵ (infants); 1.4 x 10 ⁻⁶ (children) & 2.2 x 10 ⁻⁷ (adults). Non-carcinogenic risk values (HQ):

									DDT 1 × 10 ⁻² (infants); 3 × 10 ⁻³ (children) 1.4 × 10 ⁻³ (adults).
4	(Lakhlalki et al. 2020)	El Jadida & Safi, Morocco	5 sites	May 2015 – April 2016 (all seasons)	Surface water (Oualidia lagoon)	Receives saltwater, exposed to agricultural and grazing land, polluted by runoff from septic tanks, no known recent DDT applications.	Used for oyster & cereal farming.	p.p'-DDT= 0.000023 (all seasons)	N/A

In North Africa, studies from Egypt and Morocco were found (Table 4). Studies from Egypt found DDT concentrations that were higher than the WHO guideline. Two studies were conducted in Egypt in the vicinity of three intensive agricultural or industrial areas along the Nile in one study (Dahshan et al., 2016), and a large lake in the other study (Kamel et al., 2014). Sampling in the study by Dahshan et al. (2016) took place during the dry season, which found the highest concentration, while sampling in the study by Kamel et al. (2014) took place during both the dry and wet seasons, with a slightly higher concentration found during the wet season.

In both studies, the total DDT concentrations measured during the different seasons were greater than 3 µg/l which is therefore higher than the WHO drinking water guideline for DDT. There is, however, no evidence that the water was used for drinking, as according to Dahshan et al. (2016) the water sampled from the Nile river was used for agricultural and industrial purposes, and according to Kamel et al. (2014) the water from Manzala lake was used for recreational purposes such as fishing. Interestingly, the highest DDT metabolite measured in both studies was p, p'-DDT, which indicates recent DDT application.

On the other hand, two studies were conducted in Morocco; Lakhlalki et al., (2020), which was conducted throughout all the seasons, and Berni et al., (2021), which was conducted during the wet and dry seasons. Lakhlalki et al. (2020) collected water samples from a lagoon receiving agricultural and industrial effluent and run-off, while the other study (Berni et al., 2021) sampled groundwater from wells used for drinking and agriculture in a rural area. The highest total DDT concentrations found in these studies were well below the WHO drinking water guideline threshold of 1 µg/l. The water sources sampled by Berni et al. (2021) were used to provide drinking water, and the highest concentration in this study was found during the dry season.

A health risk assessment done in the study by Berni et al. (2021), found the cancer risk values for infants (DDT & DDE= 1.8×10^{-5}) and children (DDT- 1.6×10^{-6} ; DDE- 1.4×10^{-6}) to be above the US EPA standard of 1×10^{-6} (2005) for the carcinogenic risk assessment. Thus, although the DDT concentrations found in the water samples were well below the WHO guidelines, the risk assessment indicated the water was not safe for use for infants and children. Additionally, for the non-carcinogenic risk, they found HQs of 1×10^{-2} (infants), 3×10^{-3} (children) 1.4×10^{-3} (adults) which are below the permissible guideline of one.

4. DISCUSSION

4.1 Overview of main results

This review included evidence from 20 studies conducted in 10 African countries on DDT levels detected in different water sources, and where available, health risk assessments. The countries in which the studies were conducted included; South Africa (n = 5), Nigeria (n = 3), Ghana (n = 2), Kenya (n = 2), Mozambique (n = 1), Ethiopia (n = 1), Tanzania (n = 1), Zambia (n = 1), Egypt (n = 2), and Morocco (n = 2).

4.2 Types of water sources in which DDT was detected

Table 5: Summary of the types of water samples in which DDT was detected in the different African countries

African Countries	Types of water sources
South Africa	Rivers, estuaries and tap water
Nigeria	Rivers and a reservoir
Ghana	Hand-dug wells, boreholes and rivers
Kenya	Rivers
Egypt	River and a lake
Morocco	Lagoon and wells
Ethiopia	Surface water and tap water
Mozambique	Boreholes, wells and build fountains
Tanzania	River and tributaries
Zambia	Shallow wells, open streams and tap water

The studies reviewed found the presence of DDT residues in samples of several surface water sources, reservoirs, groundwater, as well as in tap water (Table 5). The sites included those providing water used formally for drinking and recreational activities such as taps and reservoirs; groundwater often used for drinking and recreational activities by rural communities; and many surface water sites accessible to nearby communities and used for recreational activities and consumption.

In contrast to this study, evidence from reviews of studies conducted in other regions have limited data on DDT residues in drinking water. A review by Sarker et al.

(2021), which studied four South Asian countries (India, Pakistan, Nepal, and Bangladesh), included studies investigating DDT residues from rivers and lakes used to provide freshwater mostly for agricultural and industrial purposes, with some used by surrounding communities for domestic purposes.

Another review by Zhang et al. (2013), conducted in South China, evaluated studies that collected water samples from rivers, ponds, a harbour, a bay and the sea. These water sources were mainly used for fishing. Additionally, another review by Girones et al. (2020) in South America showed evidence of DDT in coast waters and sea surface water only and therefore no drinking water sources.

4.3 Seasonality of the DDT detections

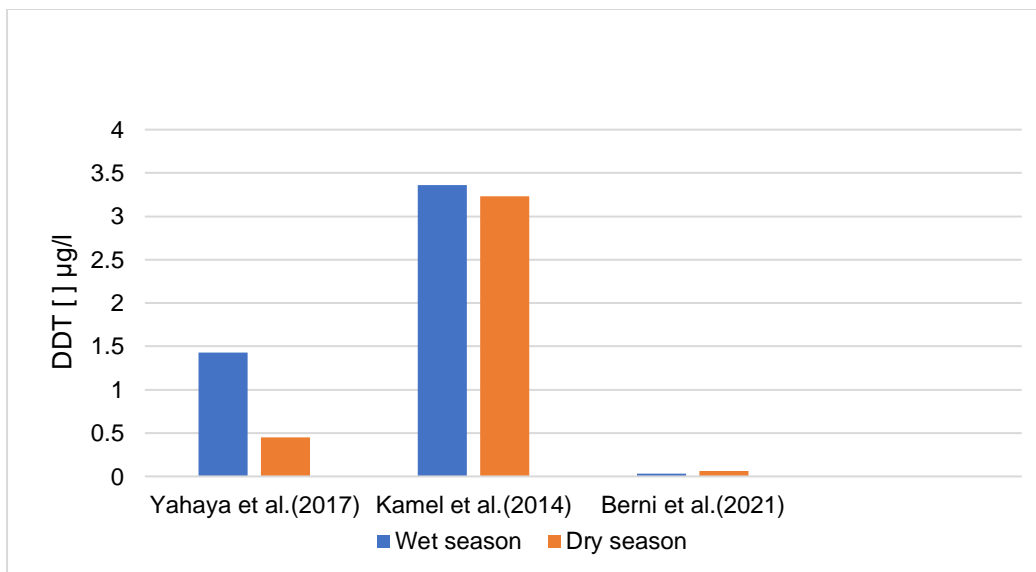


Figure 2: Comparison of DDT levels found in 3 studies that evaluated DDT both during the wet season and dry season

Three of the 20 studies in this review were conducted in both wet and dry seasons. Figure 2 above illustrates the DDT concentrations in the three studies. Higher DDT concentrations were found in the wet season in two studies conducted by Yahaya et al. (2017) and Kamel et al. (2014), in which the concentrations were greater than 1 µg/l. In contrast, a study conducted by Berni et al. (2021) found a slightly higher DDT concentration during the dry season but below 1 µg/l.

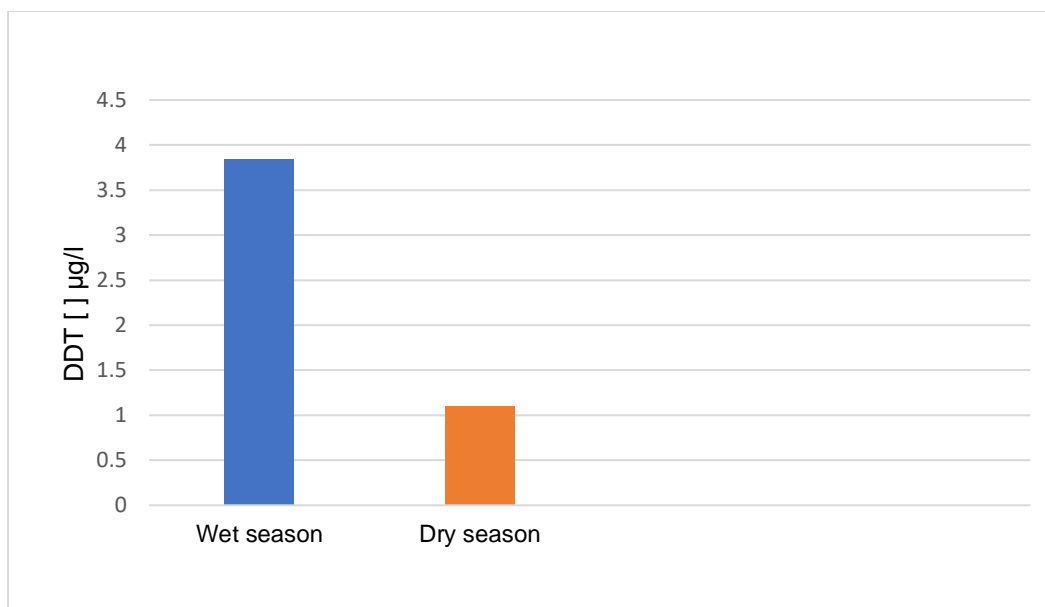


Figure 3: Comparison of DDT levels found in studies that either investigated DDT in the wet season or dry season only

Other studies conducted sampling either during the wet or the dry season (Figure 3). The median DDT concentration in two studies (Affum et al., 2018 and Van Dyk et al., 2010) that conducted sampling during the wet season was 3.84 µg/l (interquartile range (IQR): 5.72-1.96 µg/l). In contrast, the median DDT concentration in 6 studies (Olutona et al., 2014; Fosu-Mensah et al., 2016; Villanueva et al., 2021; Munyinda et al., 2015; Hellar-Kihampa et al., 2013, and Dahshan et al., 2016) that conducted sampling during the dry season only was 0.04 µg/l (IQR: 0.12-0.03 µg/l). Hence, the median DDT concentration for the wet season (3.84 µg/l) was higher than that for the dry season (0.04 µg/l) and also higher than the WHO permissible guideline of 1 µg/l.

The reason for DDT concentrations in water systems being higher during the wet seasons could be due to movement of residues in the environment from previously sprayed areas in rainfall runoff into the different water bodies (SDWF, 2016).

4.4 Evidence of human health risks due to DDT residues in African waterways

In seven of the 20 reviewed studies (Adeyinka et al., 2019; Yahaya et al., 2017; Van Dyk et al., 2010; Barnhoorn et al., 2010; Muendo et al., 2012; Dahshan et al., 2016; Kamel et al., 2014), DDT residues were detected above 1 µg/l including surface water and tap water used for drinking (Yahaya et al., 2017; Van Dyk et al., 2010;

Muendo et al., 2012; Dahshan et al., 2016). The highest total DDT concentration of 81.2 µg/l was detected in the Msunduzi river in South Africa (Adeyinka et al., 2019).

In comparison, the DDT concentrations found in the South Asia, South China, and South America reviews were lower than those found in African water systems. The highest DDT concentration found in the South Asian review, for example, was 23.6 µg/l detected in the Chilika lake in India, a source of fish for nearby communities (Sarker et al., 2021). In the South Asian review, only two rivers from India (Chilika Lake and Tapi River) had DDT concentrations greater than the WHO guideline, with neither of the rivers being a source of water for human consumption.

In the South American review, the highest level of DDT found was 0.1 µg/l in Santa Marta Bay (Girones et al., 2020), and the water sources were coastal and seawater, which are not used for human consumption. Lastly, in the South China review, the highest DDT concentration detected was 0.2 µg/l in the Shenzhen River, hence the DDT levels from all the sites were lower than the WHO guideline. There is no evidence that the water from the study sites in the South China review was used directly for human consumption, although the fish from some of the water sources were consumed by nearby communities (Zhang et al., 2013). All the DDT residue concentrations detected in studies from other geographic regions in non-potable water were therefore, lower than the WHO guideline.

Five studies included in this review conducted human health risk assessments. The DDT concentrations detected in all the latter studies were below the WHO guidelines except for the study conducted by Yahaya et al. (2017) in South Africa (DDT concentration = 1.43 µg/l). Two studies by Affum et al. (2018) and Berni et al. (2021) found the cancer risk for infants and children consuming sampled water, to be higher than the US-EPS (2005) acceptable level (1×10^{-6}). The cancer risk for adults in the latter studies were lower than the acceptable level (Affum et al., 2018; Berni et al., 2021). The cancer risk for water from the Sundays and Swartkops estuaries, a water source for bathing and drinking, in the study by Olisah et al. (2019), was lower than the permissible guideline of 1×10^{-6} for drinking and bathing water.

The HQ for non-carcinogenic risks for DDT concentrations in water in the studies by Olisah et al. (2019) was below one, for both drinking and bathing water in both

estuaries. Moreover, three studies (Yahaya et al., 2017; Berni et al., 2021; Ogbeide et al., 2015^b) also found HQs for non-carcinogenic risks below one. This African review therefore provides more evidence of risks to human health due to DDT residues in waterways than reviews in other regions, which could indicate that African populations are more exposed to DDT from water pollution.

4.5 Limitations in studies reviewed

This review found studies conducted only in 10 African countries, with no studies identified in the other 42 African countries, and hence the review is not representative of all African countries. Although there was representation from Eastern, Western, Northern and Southern African regions, the number of studies in the different regions varied with 50% of the studies conducted in South Africa (25%), and Western African countries (Nigeria & Ghana) (25%).

Only two studies (Olisah et al. 2019 and Lakhlalki et al., 2020) out of the 20, conducted sampling across all the different seasons of the year, hence most of the studies did not measure DDT levels over different seasons. Furthermore, most studies did not collect water samples from multiple water sources in the study areas, with only four studies (Affum et al. (2018), Villanueva et al. (2021), Loha et al. (2020) and Munyinda et al. (2015)) that conducted monitoring from a range of different water sources. Moreover, in 12 studies (60%), the number of samples collected were not stated, hence it cannot be confirmed whether the number of samples were sufficient enough to give reliable results. Lastly, as mentioned previously, only five studies conducted risk assessments, while most of the studies that had DDT concentrations higher than the WHO guideline of 1 µg/l did not conduct risk assessments.

5. CONCLUSION

This review of 20 African studies found the presence of DDT residues in multiple water sources in African water systems, with most of the detections occurring at variable concentrations throughout the year. The water sources included surface water, groundwater, and water reservoirs used for drinking water. The DDT residues were detected in water samples in settings where DDT is sprayed for malaria vector

control or where it was previously used (e.g. for agriculture). The Evidence of risks to human health was found as the concentration of DDT residues exceeded the WHO drinking water guidelines and/or cancer permissible limits in many sampled drinking sources.” Alternative methods for malaria vector control should be investigated for application in Africa and other regions where it is used. Larger studies conducting seasonal monitoring of DDT residues in multiple water sources, including drinking water, and including risk assessment, are recommended.

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Part C: Appendices

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Appendix A: Letter from the University of Cape Town Human Research Ethics Committee (HREC)



UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee



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Website: www.health.uct.ac.za/fhs/research/humanethics/forms

26 February 2021

HREC REF: 462/2021

Prof A Dalvie
Centre for Environmental and Occupational Health Research
Public Health & Family Medicine
Email PI: aqiel.dalvie@uct.ac.za

Dear Prof Dalvie

PROJECT TITLE: LITERATURE REVIEW ON THE HEALTH RISKS DUE TO WATER POLLUTION BY DDT AND THE IMPACT ON WATER QUALITY ACCESS (MASTERS CANDIDATE MS LETHABO MAKGOBA)

Thank you for submitting your systematic review to the Faculty of Health Sciences Human Research Ethics Committee.

The HREC note that the proposed study is a systematic review.

As the systematic review involves published literature available through publicly accessible electronic databases, research ethics review and approval is not required.

This is in accordance with Section 1.1.8 of the Department of Health's Ethics in Health Research: Principles, Processes and Structures (South African Department of Health, 2015), which states: *"Research that relies exclusively on publicly available information or accessible through legislation or regulation usually need not undergo formal ethics review. This does not mean that ethical considerations are irrelevant to the research."*

The HREC recommend that researchers refer to the PRISMA website, for the PRISMA statement and checklist, to facilitate the reporting of systematic reviews and meta-analyses. For more information, please refer to <http://www.prisma-statement.org/>.

Further, fundamental ethical principles for health-related research should be considered in the objectives and methods of the systematic review. See, for example, the Declaration of Helsinki (Fortaleza, Brazil, 2013) and the Department of Health's Ethics in Health Research: Principles, Processes and Structures (South African Department of Health, 2015).

The HREC acknowledges that the Masters Candidate Ms Lethabo Makgoba is also involved in this study.

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FACULTY OF HEALTH SCIENCES HUMAN RESEARCH ETHICS COMMITTEE

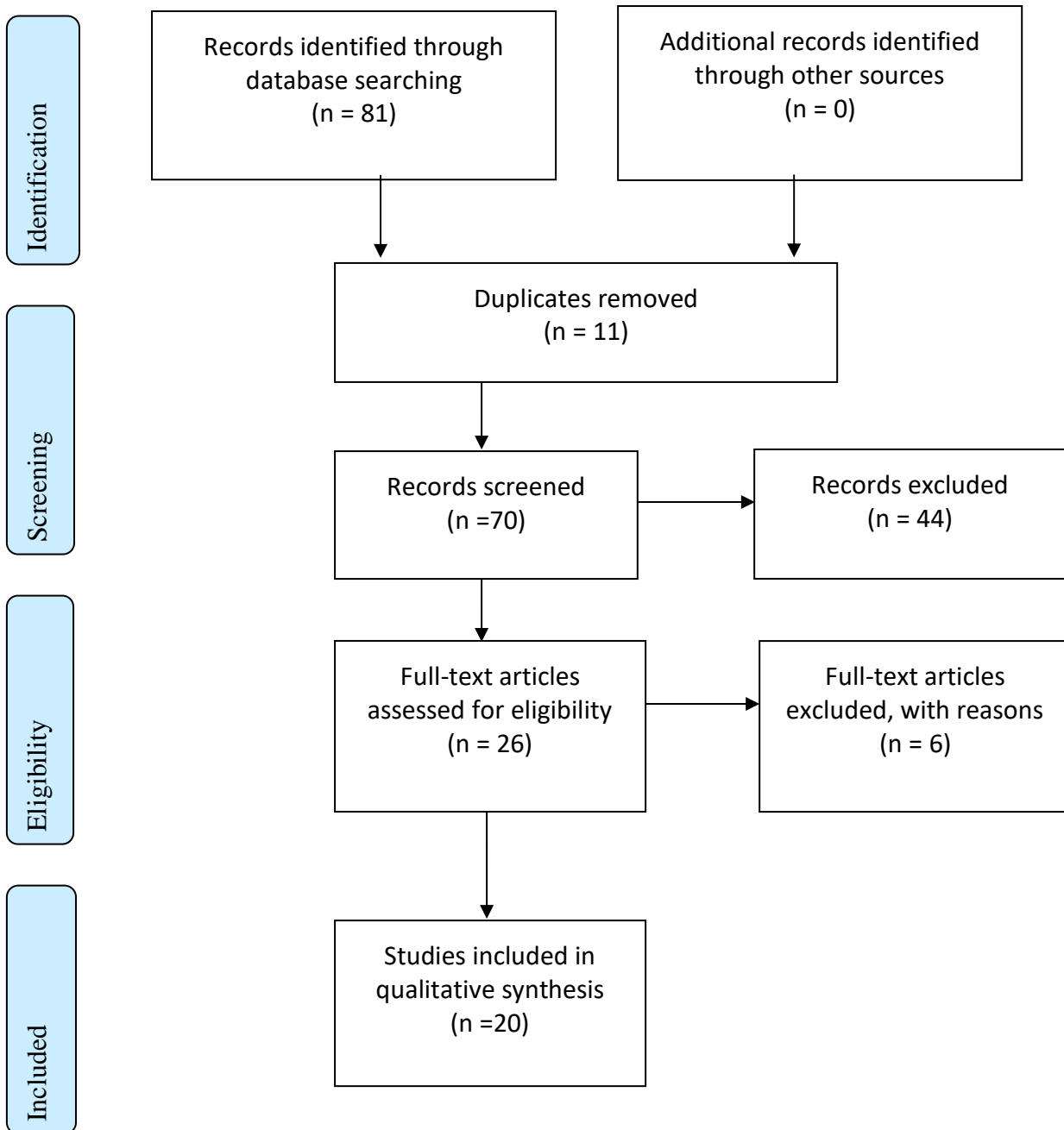
HREC REF NO. 462/2021

Appendix B: Electronic search of databases for published, peer-reviewed articles and keywords used.

	Database	Keywords
1.	PubMed	((((DDT OR 4,4'-Dichlorodiphenyltrichloroethane OR 4,4' Dichlorodiphenyltrichloroethane) OR (DDT[MeSH Terms])) AND ((Water Pollution OR Water Pollutants OR Groundwater OR Drinking Water OR Water OR Water Resources OR Waste Water OR Water Quality[MeSH Terms]) OR (water contamination OR water pollution OR water sources OR water OR water system OR water systems OR wastewater OR waste-water))) AND ((risk OR risks OR risk assessment OR health assessment OR health risk OR health risks OR health effect OR health effects) OR (Risk OR Risk Assessment[MeSH Terms])) NOT ((Animals[MeSH Terms]) NOT (Humans[MeSH Terms])) AND (Africa OR African OR Algeria OR Angola OR Benin OR Botswana OR Burkina Faso OR Burundi OR Cameroon OR "Canary Islands" OR "Cape Verde" OR "Central African Republic" OR Chad OR Comoros OR Congo OR "Democratic Republic of Congo" OR Djibouti OR Egypt OR Eritrea OR Ethiopia OR Gabon OR Gambia OR Ghana OR Guinea OR "Ivory Coast" OR "Cote d'Ivoire" OR Jamahiriya OR Kenya OR Lesotho OR Liberia OR Libya OR Madagascar OR Malawi OR Mali OR Mauritania OR Mauritius OR Mayotte OR Morocco OR Mozambique OR Namibia OR Niger OR Nigeria OR Principe OR Reunion OR Rwanda OR "Sao Tome" OR Senegal OR Seychelles OR "Sierra Leone" OR Somalia OR "St Helena" OR Sudan OR Swaziland OR Tanzania OR Togo OR Tunisia OR Uganda OR "Western Sahara" OR Zaire OR Zambia OR Zimbabwe AND (English[Filter])) Filters: English, from 2010/1/1 - 2021/6/30
2.	Scopus	((TITLE-ABS-KEY (4,4'-dichlorodiphenyltrichloroethane OR dichlorodiphenyltrichloroethane OR ddt)) AND (TITLE-ABS-KEY (risk OR risks OR "risk assessment" OR "health assessment" OR "health risk" OR "health risks" OR "health effect" OR "health effects")) AND (TITLE-ABS-KEY ("water contamination" OR "water pollution" OR "water sources" OR water OR "water system" OR "water systems" OR wastewater OR waste-water)) AND (TITLE-ABS-KEY (africa OR african OR algeria OR angola OR benin OR botswana OR burkina AND faso OR burundi OR cameroon OR "Canary Islands" OR "Cape Verde" OR "Central African Republic" OR chad OR comoros OR congo OR "Democratic Republic of Congo" OR djibouti OR egypt OR eritrea OR ethiopia OR gabon OR gambia OR ghana OR guinea OR "Ivory Coast" OR "Cote d'Ivoire" OR jamahiriya OR kenya OR lesotho OR liberia OR libya OR madagascar OR malawi OR mali OR mauritania OR mauritius OR mayotte OR morocco OR mozambique OR namibia OR niger OR nigeria OR principe OR reunion OR rwanada OR "Sao Tome" OR senegal OR seychelles OR "Sierra Leone" OR somalia OR "St Helena" OR sudan OR swaziland OR tanzania OR togo OR tunisia OR uganda OR "Western Sahara" OR zaire OR zambia OR zimbabwe))) AND NOT (INDEXTERMS (animals AND NOT humans)) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (PUBYEAR , 2009))

3.	Web of Science	<p>(((((TS=(4,4'-Dichlorodiphenyltrichloroethane OR Dichlorodiphenyltrichloroethane OR DDT)) AND TS=("water contamination" OR "water pollution" OR "water sources" OR "water system" OR "water systems" OR wastewater OR "waste-water")) AND TS=(risk OR risks OR "risk assessment" OR "health assessment" OR "health risk" OR "health risks" OR "health effect" OR "health effects")) AND TS=(Africa OR African OR Algeria OR Angola OR Benin OR Botswana OR Burkina Faso OR Burundi OR Cameroon OR "Canary Islands" OR "Cape Verde" OR "Central African Republic" OR Chad OR Comoros OR Congo OR "Democratic Republic of Congo" OR Djibouti OR Egypt OR Eritrea OR Ethiopia OR Gabon OR Gambia OR Ghana OR Guinea OR "Ivory Coast" OR "Cote d'Ivoire" OR Jamahiriya OR Kenya OR Lesotho OR Liberia OR Libya OR Madagascar OR Malawi OR Mali OR Mauritania OR Mauritius OR Mayotte OR Morocco OR Mozambique OR Namibia OR Niger OR Nigeria OR Principe OR Reunion OR Rwanda OR "Sao Tome" OR Senegal OR Seychelles OR "Sierra Leone" OR Somalia OR "St Helena" OR Sudan OR Swaziland OR Tanzania OR Togo OR Tunisia OR Uganda OR "Western Sahara" OR Zaire OR Zambia OR Zimbabwe)) NOT TS=(animals NOT humans) and 2002 or 2003 or 2004 or 2005 or 2006 or 2007 or 2009 (Exclude – Publication Years) and MEDLINE® (Exclude – Database) and English (Languages)</p>
4.	EBSCO Host	<p>((DDT OR 4,4'-Dichlorodiphenyltrichloroethane OR 4,4' Dichlorodiphenyltrichloroethane)) AND ((risk OR risks OR "risk assessment" OR "health assessment" OR "health risk" OR "health risks" OR "health effect" OR "health effects")) AND (("water contamination" OR "water pollution" OR "water sources" OR water OR "water system" OR "water systems" OR wastewater OR waste-water)) AND ((Africa OR African OR Algeria OR Angola OR Benin OR Botswana OR Burkina Faso OR Burundi OR Cameroon OR "Canary Islands" OR "Cape Verde" OR "Central African Republic" OR Chad OR Comoros OR Congo OR "Democratic Republic of Congo" OR Djibouti OR Egypt OR Eritrea OR Ethiopia OR Gabon OR Gambia OR Ghana OR Guinea OR "Ivory Coast" OR "Cote d'Ivoire" OR Jamahiriya OR Kenya OR Lesotho OR Liberia OR Libya OR Madagascar OR Malawi OR Mali OR Mauritania OR Mauritius OR Mayotte OR Morocco OR Mozambique OR Namibia OR Niger OR Nigeria OR Principe OR Reunion OR Rwanda OR "Sao Tome" OR Senegal OR Seychelles OR "Sierra Leone" OR Somalia OR "St Helena" OR Sudan OR Swaziland OR Tanzania OR Togo OR Tunisia OR Uganda OR "Western Sahara" OR Zaire OR Zambia OR Zimbabwe)) NOT (animals NOT humans)</p> <p>Limiters - Published Date: 20100101-20210631</p> <p>Expanders - Apply equivalent subjects</p> <p>Narrow by Language: - English</p> <p>Search modes - Boolean/Phrase</p>

Appendix C: Prisma Flow diagram



Appendix D: Data Extraction Table

	Articles				
Author name (s) & Year of publication					
Article title					
Aim					
Methods					
Study setting/location					
DDT levels/presence in water sources.					
Type of water source					
Uses of water source					
Human exposure to water source/ Health risk assessment.					

Appendix E: Detailed summary of studies reviewed

E.1. Studies exploring DDT levels in the waterways of South Africa

Author name(s)	Olisah, C., Adeniji, A. O., Okoh, O. O., Okoh, A. I (2019)
Article title	“Occurrence and risk evaluation of organochlorine contaminants in surface water along the course of Swartkops and Sundays River Estuaries, Eastern Cape Province, South Africa.”
Aim	The aim of the study was to analyse organochlorine contaminants in surface water from Sundays (SDE) and Swartkops Estuaries (SWE), Eastern Cape Province, which is among the largest estuaries in South Africa.
Methods	<ul style="list-style-type: none"> • Surface water from the Sundays (SDE) and Swartkops Estuaries (SWE) in the Eastern Cape Province was tested for organochlorine pollutants. • 400 samples were analysed for DDT metabolites, in the autumn (March–May; 60 samples), winter (July–August; 40 samples), spring (September–November; 60 samples), and summer (January–February; 40 samples). • Surface water samples were taken from five different sites at SDE and SWE. • Phenomenex—Strata C18 was used for solid phase extraction (SPE) and sample cleaning. • The organochlorine contaminants in the water extracts were analysed with an Agilent 7820A GC coupled with I-ECD fitted with an Agilent HP-5 - 60 to 325 C GC column (30 m 9 320 lm 9 0.25 lm film thickness). • Lastly, carcinogenic, and non-carcinogenic risk assessment of DDT and its metabolites were evaluated using a model proposed by US EPA.
DDT level/presence in water sources	<ul style="list-style-type: none"> • Among all OCPs, p,p-DDE and p,p-DDT were found in the highest concentrations in surface water samples from SDE and SWE. • DDT concentrations were higher in SWE than in SDE throughout all four seasons. • DDD and DDE/DDTs values in both estuaries varied from 0.0003 - 0.0008 µg/l, 0.0001–0.001 µg/l, 0.0003–0.0001 µg/l, and 0.0002–0.0001 µg/l, respectively, for autumn, winter, spring, and summer. • In SDE, the concentrations of total DDTs ranged from 0.00133 to 0.0835 µg/l in autumn; 0.0061 to 0.0214 µg/l in winter, 0.0011 to 0.0152 µg/l in spring and 0.0016 to 0.0269 µg/l in summer. • For SWE, mean concentrations of 0.0367 ± 0.0301 µg/l, 0.133 ± 0.0325 µg/l, 0.032 ± 0.025 µg/l and 0.0155 ± 0.0103 µg/l were recorded in autumn, winter, spring and summer, respectively. • Mean ΣDDT: Summer (wet season)= 0.015 ±0.0149 µg/l; Autumn (pre-dry season)= 0.0507±0.0326 µg/l; Winter (dry season) = 0.0178±0.0066 µg/l, Spring (pre-wet season)= 0.0088±0.0077 µg/l.
Type of water source	Surface water from two estuaries
Uses of water source	Agricultural purposes and also used for drinking and bathing
Sources of water contamination	<ul style="list-style-type: none"> • Discharge of solid and industrial pollutants. • Discharges from fish flat sewage works, motor industries, farmlands, power plants, brick-making enterprises and mining, railways and depots.

Human exposure to water source	<ul style="list-style-type: none"> For the carcinogenic and non-carcinogenic risk assessment, the risk hazard values for DDTs in SDE ranged from 1.54×10^{-3} to 3.38×10^{-3} in drinking water, and from 6.70×10^{-6} to 1.47×10^{-5} in bathing water. On the other hand in SWE the values ranged from 3.61×10^{-3} to 8.84×10^{-3} in drinking water and from 1.57×10^{-5} to 3.85×10^{-5} in bathing water.
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Author name(s)	Adeyinka, G. C., Moodley, B., Birungi, G., Ndungu, P (2019)
Article title	“Evaluation of organochlorinated pesticide (OCP) residues in soil, sediment, and water from the Msunduzi River in South Africa.”
Aim	The aim of the study was to investigate the presence and concentration levels of selected OCP residues in sediment, soil and surface water of the Msunduzi River as well as samples from Darvill waste water treatment plant during winter and spring seasons
Methods	<ul style="list-style-type: none"> Msunduzi River and Darvill WWTP were studied in the Pietermaritzburg watershed region of KwaZulu-Natal, South Africa. Samples were taken from soil, sediment, and water between the 16th–17th of July and the 25th–26th of September 2013 for the winter and spring seasons, respectively. The samples were collected in Msunduzi town (MST), Du Toit (DUT), Henley dam outlet (HND), agricultural area (AGR), Nagle Dam (NGD), WWT 1, WWT 2, Camps drift (CMD) and Umgeni–Msunduzi. The total number of samples is not stated. The samples were extracted with dichloromethane using an ultrasonication process, cleaned up with multi-layered silica gel, and analysed using gas chromatography-mass spectrometry, according to the USEPA standard sampling procedure.
DDT level/presence in water sources	<ul style="list-style-type: none"> DDT and its metabolites were the most prevalent among the OCPs tested in both seasons for water samples. To analyse the trend of DDT sources in water, the ratios of DDE/ ΣDDTs and DDD/ Σ DDTs were calculated, yielding values of 1.56 and 2.90, and 1.61 and 2.62, respectively, during the winter and spring seasons. In winter (dry season) the minimum and maximum levels ($\mu\text{g ml}^{-1}$) of DDT and its metabolites according to different locations were; o,p-DDE: 5.56 ± 0.05 (MST) to 14.04 ± 0.68 (WWT2) ; p,p-DDE: 10.89 ± 0.11 (MST) to 27.5 ± 1.19 (WWT2) ; o,p-DDD: 11.46 ± 0.04 (MST) to 16.36 ± 0.22 (HND) ; o,p-DDT: 0.85 ± 0.68 (WWT2) to 10.11 ± 0.9 (DUT) ; p,p-DDD: 2.01 ± 0.82 (MST) to 28.87 ± 0.48 (WWT2) ; p,p-DDT: 2.09 ± 0.52 (AGA) to 19.95 ± 0.12 (NGD). In spring (pre-wet season) the minimum and maximum levels were ($\mu\text{g ml}^{-1}$); o,p-DDE: 0.27 ± 1.78 (CMD) to 14.68 ± 0.26 (WWT1) ; p,p-DDE: 7.49 ± 0.02 (CMD) to 40.47 ± 0.27 (WWT1) ; o,p-DDD: 0.94 ± 0.46 (WWT3) to 14.76 ± 0.46 (WWT1) ; o,p-DDT: 0.08 ± 0.19 (DUT) to 16.67 ± 1.42 (WWT1) ; p,p-DDD: 6.84 ± 0.22 (CMD) to 81.15 ± 0.25 (WWT1) ; p,p-DDT: 0.72 ± 0.95 (CMD) to 36.19 ± 0.33 (WWT1).
Type of water source	Surface water, rivers.
Uses of water source	The river is the major source of water to the larger population of the area.
Sources of water contamination	Receives effluent from untreated domestic waste from rural areas (sewage), unmanaged municipal waste dumps as well as agricultural drainage.

Human exposure to water source	No mention of human exposure
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Author name(s)	Yahaya, A., Okoh, O.O., Okoh, A. I., Adeniji , A. O (2017)
Article title	“Occurrences of Organochlorine Pesticides along the Course of the Buffalo River in the Eastern Cape of South Africa and Its Health Implications.”
Aim	The aim of the study was to evaluate the concentrations of 17 OCPs in surface water samples collected from six sampling sites along the course of the Buffalo River in Eastern Cape, South Africa
Methods	<ul style="list-style-type: none"> The study was conducted at Buffalo River in the Eastern Cape province of South Africa, at six sampling sites; Maden dam (MD), Izele River (IZ), King William’s town (KWT), Zwelitsha (ZW), and Mdantsane (MSN), and Buffalo river estuary (BRE). Grab samples of surface water were taken in triplicate at a depth of 100 mm below the water surface at each of the six sampling sites and placed in pre-cleaned amber bottles. From December 2015 to May 2016, samples were taken early in the morning (7–10 a.m.) and stored in 5 mL of hydrochloric acid (1:1). They were immediately brought to the laboratory for examination after being kept in ice chests at 4°C. OCPs were then analysed using a micro-ECD system and an Agilent 7820A GC (Agilent Technologies, Johannesburg, South Africa) (Model G2397AE, Santa Clara, CA, USA).
DDT level/presence in water sources	<ul style="list-style-type: none"> The concentrations of DDT metabolites during the summer sampling were as follows; 4,4-DDE was only found only in ZW at a mean \pm SD concentration of 234 ± 0.01 ng/l. 4,4 DDD was detected in BRE (34 ± 0.01 ng/l), MSN (494 ± 0.01 ng/l), ZW (121 ± 0.12 ng/l) and IZ (331 ng/l). And 4,4-DDT was detected only in ZW (218 ± 0.12). On the other hand the concentrations of DDT metabolites during the autumn sampling were as follows; 4,4-DDE was only found only in ZW at a mean \pm SD concentration of 201 ± 0.01 ng/l. 4,4 DDD was detected in BRE (36 ± 0.02 ng/l), MSN (79 ± 0.06 ng/l), ZW and IZ (53 ± 0.03 ng/l). And 4,4-DDT was detected in MSN (44 ± 0.03 ng/l) and IZ (40 ± 0.26 ng/l). <p>Summer (wet season) \sumDDT = 1.432 ± 0.00027 μg/l; Autumn (dry season) \sumDDT = 0.453 ± 0.00041 μg/l</p>
Type of water source	Surface water from the river
Uses of water source	Domestic and agricultural purposes.
Sources of water contamination	<ul style="list-style-type: none"> Pollutants from domestic and industrial sources. Toxic leachates containing heavy metals from a former tannery dump site. Contaminated run-off from human activities such as various operational spillages and ship repair, effluents containing several hazardous chemicals from some wastewater treatment plants and industries.

Human exposure to water source	<ul style="list-style-type: none"> For the risk assessment the Hazard quotient for DDT metabolites were as follows according to different age group; 4,4-DDE: $(14,751 \times 10^{-6})$, (8741×10^{-6}) and (2950×10^{-6}) for age groups 0-6, 7-17 and adults, respectively. 4,4-DDD: (8306×10^{-6}), (4922×10^{-6}) and (1661×10^{-6}) for age groups 0-6, 7-17 and adults, respectively. 4,4-DDT: (12×10^{-6}), (7×10^{-6}) and (2×10^{-6}) for age groups 0-6, 7-17 and adults, respectively.
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Author name(s)	Van Dyk, J. C., Bouwman, H., Barnhoorn, I. E. J., Bornman, M. S (2010)
Article title	“DDT contamination from indoor residual spraying for malaria control.”
Aim	The aims of this study were to determine the levels of DDT contamination, as a result of IRS, in representative homesteads, and to evaluate the possible routes of human exposure.
Methods	<ul style="list-style-type: none"> The study area is in the Vhembe District of South Africa's Limpopo Province. Two communities were chosen as exposed (DV) and reference (TV). Sampling was done during the summer season, two months after the IRS process in DV was completed by the spray-team in February 2008. Twelve homesteads (D1-D12) were chosen in DV, whereas nine were selected in TV (T1-T9). DDT, DDD, and DDE o,p'- and p,p'-isomers were analyzed in one 2500 mL sample of drinking water obtained from each household in pre-cleaned glass bottles. Water samples (n=12) were collected directly from the DV community tap and the Luvuvhu River nearby.
DDT level/presence in water sources	<ul style="list-style-type: none"> The mean concentration of DDT in potable water was determined to be $2.0 \mu\text{g L}^{-1}$. In DV, 83% of water samples contained o,p'- and p,p'-DDT, as well as p,p'-DDE, but no measurable amounts of DDT or its metabolites were found in TV water samples. The DDT levels identified in the drinking water samples from DV were primarily p,p'- and o,p'-DDT, with values ranging from $0.6 \mu\text{g L}^{-1}$ to $7.6 \mu\text{g L}^{-1}$. The bulk of the water samples (83.3 %) had DDT levels below the World Health Organization's (WHO) drinking water guideline threshold of $2 \mu\text{g L}^{-1}$. <p>ΣDDT min-max values was (0.6–7.6) -wet season.</p>
Type of water source	Community taps and river
Uses of water sources	Drinking water
Sources of water contamination	DDT from IRS
Human exposure to water source	No mention of human exposure

Author name(s)	Barnhoorn, I. E. J., van Dyk, J. C., Pieterse, G.M., Bornman, M. S (2010)
Article title	“Intersex in feral indigenous freshwater <i>Oreochromis mossambicus</i> , from various parts in the Luvuvhu River, Limpopo Province, South Africa.”
Aim	The aim of the study was to report on testicular oocytes in <i>O. mossambicus</i> and detected levels of selected EDCs in mesenteric fat, water, and sediment samples.
Methods	<ul style="list-style-type: none"> • The research was done in the Luvuvhu River, three locations were sampled: Nandoni Dam (a DDT exposure site), Xikundu Weir (a downstream DDT sprayed region), and Albasini Dam (Refence site). • Surface water from the selected sites in the Luvuvhu River catchment was collected in 1 L glass bottles that had been pre-washed with ethanol throughout the course of four surveys. • The number of samples collected and the season in which the samples were collected are not stated in the paper. • Prior to sample preparation for OC and AP tests, all water samples were held at 4°C in the laboratory. • Gas chromatography-mass spectrometry was used to analyse and quantify the OCs.
DDT level/presence in water sources	<ul style="list-style-type: none"> • All six DDT isomers were present in one or more samples from the three sites, but not during the same survey and at levels just above the detection limit. • In survey 1 only p,p'-DDD was detected above the detection limit of 0.1 µg/l in Nandoni Dam at a concentration of 0.12 µg/l. • In survey 2 only p,p'-DDE was detected above the detection limit of 0.1 µg/l in Nandoni Dam and Xikundu Weir at a concentrations of 0.3 and 0.4µg/L, respectively. • In survey 3, all DDT metabolites were detected in Albasini Dam; o,p'-DDE (1 µg/l), p,p'-DDE (1 µg/l), p,p'- DDT (0.3 µg/l) and the total DDT concentration in this river was 2.3 µg/l. In this same survey p,p'-DDE was detected in Nandoni Dam (1.1 µg/l). • In survey 4 only p,p'-DDE (1 µg/l) was detected in Albasini Dam, then o,p'-DDE (1.2 µg/l) and p,p'-DDE (1 µg/l) were detected in Xikundu Wier and the total DDT concentration was 2.2 µg/l.
Type of water source	Surface water (rivers)
Uses of water source	The river is a major supply of fresh water in the Vhembe area of South Africa's Limpopo Province and it is also used for recreational purposes.
Sources of water contamination	Runoff from indoor residual spraying
Human exposure to water source	A human exposure risk was not done for this study.

E.2. Studies exploring DDT levels in the waterways of Nigeria

Author name(s)	Ogbeide, O., Tongo, I., Ezemonye, L (2015 ^a)
Article title	“Risk assessment of agricultural pesticides in water, sediment, and fish from Owan River, Edo State, Nigeria.”
Aim	The aim of the study was to evaluate the concentration of pesticide residues in the Owan River and also the dietary intake of pesticide residues in fish obtained from the Owan River.
Methods	<ul style="list-style-type: none"> • The study area was the Owan River which is one of the major rivers in Edo State. • It is located in Owan town, an ecological zone of Edo State’s Forest belt, and is best known for cocoa, plantain, and pepper cultivation. • A total of 72 water samples from surface water were collected between January 2012 and June 2013 • A total of 16 pesticides were examined using gas chromatography (GC) with an electron capture detector (ECD). • Water samples were taken from 0.3 m below the water surface using hydrobios and a pre-cleaned glass, following the procedure developed by Ezemonye et al. • Pesticide concentrations were measured using a Hewlett-Packard (hp) 5890 Series II fitted with a 63Ni electron capture detector (ECD) with an auto sampler and an activity of 15 mCi.
DDT level/presence in water sources	In water samples a Mean ± SD of 0.12±0.06 (µg/l) for DDT was found throughout all seasons.
Type of water source	River
Uses of water source	Agricultural purposes.
Sources of water contamination	Agrochemicals from commercial cocoa farms.
Human exposure to water source	There was no mention of human risk/ exposure but a potential risk assessment for consumption of fish was done for other pesticide either than DDT.

Author name(s)	Ogbeide, O., Tongo, I., Enuneku, A., Ogbomida, E., Ezemonye, L (2015 ^b)
Article title	“Human Health Risk Associated with Dietary and Non-Dietary Intake of Organochlorine Pesticide Residues from Rice Fields in Edo State Nigeria.”
Aim	The aim of the study was to monitor 14 organochlorine pesticides in water, sediment, and biota collected from the Illushi River Basin
Methods	<ul style="list-style-type: none"> • The quantities, distribution patterns, ecological danger, and human health risk of fourteen organochlorine pesticides were evaluated in surface water, sediment, and fish taken from a large rice field in Illushi. • The research was conducted in the Illushi River basin, which is located in a rice field in Edo State, Nigeria. • Samples for analysis were gathered during an 18-month period, from January 2012 to June 2013. • Water samples (n = 216) were collected from 0.3 m below the water surface using a pre-cleaned glass bottle and a hydro bios sample, as described by Ezemonye et al. • The samples were extracted and evaluated using gas chromatography fitted with an electron capture detector, and the risk was assessed using conventional models (risk quotient and Chronic daily intake).
DDT level/presence in water sources	The Mean ± SD concentrations of DDT in water were found to be 0.09 ± 0.19 (µg/l) throughout all seasons.
Type of water source	Surface water in a river
Uses of water source	Drinking water and agricultural purposes.
Sources of water contamination	Pesticide runoff from rice farms
Human exposure to water source	<ul style="list-style-type: none"> • The chronic daily intake (ingestion) of DDT in water in children and adults is 7.88E-06 and 2.28E-06, respectively • Hazard quotient for DDT is 0.0158 and 0.0046, respectively.

Author name(s)	Olutona, G. O., Ayanoa, S. A., Obayomi-Davies, O (2014)
Article title	“Organochlorine pesticide in water and bottom sediment from Aiba Reservoir (Southwestern Nigeria).”
Aim	The aim of the study was to investigate the pollution status of the reservoir water and the bottom sediment.
Methods	<ul style="list-style-type: none"> • The research site was the Aiba reservoir, a small tropical man-made lake in Iwo, Nigeria's southwestern region. • Four sample areas in the reservoir were chosen: the entry point, the upper region, the agricultural area, and the spillway area. • Water samples were collected in sterile 2.5 L Winchester bottles for each of the four locations in November and December 2012. • The OCP were extracted from water samples using liquid-liquid extraction, and gas chromatography was used to evaluate the presence and amounts of the organochlorines in both the surface water and bottom sediment of Aiba reservoir.
DDT level/presence in water sources	<ul style="list-style-type: none"> • pp-DDT was detected in 37% and 50% of the water and soil samples, respectively. • Its metabolites, pp-DDD and pp-DDE, were discovered in 25% of the soil and water samples. • DDT and its metabolites were found in water samples at the following values (mean \pm sd, $\mu\text{g/l}$): pp-DDD (0.03 ± 0.06), pp-DDE (0.04 ± 0.07) and pp-DDT (0.05 ± 0.08). • ΣDDT concentration = $0.12 \mu\text{g/l}$ (dry season).
Type of water source	Reservoir
Uses of water source	Created primarily for the provision of portable water
Sources of water contamination.	<ul style="list-style-type: none"> • Anthropogenic activities including, intense fishing activity, agricultural practices, washing of domestic wares and automobiles, bathing and fetching of water for construction and domestic purposes.
Human exposure to water source	No mention of human exposure.

E.3. Studies exploring DDT levels in the waterways of Ghana

Author name(s)	Affum, A. O., Acquah, S. O., Osa, S. D., Kwaansa-Ansah, E. E (2018)
Article title	“Distribution and risk assessment of banned and other current-use pesticides in surface and groundwaters consumed in an agricultural catchment dominated by cocoa crops in the Ankobra Basin, Ghana.”
Aim	The aim of the study was to screen for banned pesticides, non-banned pesticides and their metabolites in the ground water and surface water sources in the agricultural catchment of Ankobra Basin
Methods	<ul style="list-style-type: none"> • This study was carried out in Ghana's Western Region, where water samples were collected from an agricultural catchment inside the Ankobra River Basin's Forest ecological zone. • From August to October 2016, 44 duplicate water surface and ground water samples were randomly collected from 11 rural communities in the Ankobra Basin, including public boreholes (B1-B11), the Peme River (S2 and S7), the Ben River (S10), and their adjoining streams (S1 to S6, S8, S9, and S11) neighbouring to cocoa farms. • The pesticides (including DDT) found in the water samples were tested at a pesticide laboratory that is accredited and adheres to the DIN EN ISO/IEC 17025:2005 standards and pesticides in surface water and groundwater were assessed for human health risks.
DDT level/presence in water sources	<ul style="list-style-type: none"> • p,p'-DDT was deducted in both ground and surface water. • p,p'-DDT had the highest concentrations in the surface and groundwater samples (0.110 µg/l) in a smaller tributary of Ben River and (0.055 µg/l) in a borehole (drinking water), respectively. • The ΣDDTs in ground water and surface water was 0.055 µg/l and 0.08 µg/l respectively for wet seasons.
Type of water sources	Ground water (borehole) and surface water (rivers)
Uses of water sources	Drinking purposes
Sources of water contamination	<ul style="list-style-type: none"> • Agricultural runoff from cocoa farms, • Pesticide contamination from poor pesticide management by farmers, • Human activities
Human exposure to water source	<ul style="list-style-type: none"> • The carcinogenic risk of p,p'-DDT, p,p'-DDE, p,p'-DDE, in infants, adults, and children who drink from the surface water sources was higher than that from the groundwater sources. In this regard, a higher cancer risk due to p,p'- DDT was found at B1 (infants: 2.8×10^{-5}; children: 1.5×10^{-6}) and B6 (infants: 7.7×10^{-6}; children: 5.6×10^{-6}). • For surface water sources, a high cancer risk due to p,p'-DDT (infants: 5.1×10^{-6} to 1.28×10^{-5}; children: 1.56×10^{-6} to 2.55×10^{-6}), was found at S1–S9. • Meanwhile, a higher cancer risk due to p,p'-DDD (infants: 1.8×10^{-5}; children: 3.6×10^{-6}), p,p'-DDE (infants: 2.6×10^{-6}; children: 2.6×10^{-6}) was found at S1.

- The pesticides were of low risk to humans that consume the water but considering the US EPA safe limit for carcinogenic effects of 10^{-6} , the high levels of DDTs, β -HCH, and dieldrin in some of the surface water and groundwater sources may cause cancer in children or infants.

Author name(s)	Fosu-Mensah, B. Y., Okoffo, E. D., Darko, G., Gordon, C (2016)
Article title	“Assessment of organochlorine pesticide residues in soils and drinking water sources from cocoa farms in Ghana.”
Aim	The aim of the study was to assess 15 organochlorine pesticide residues in soils and drinking water sources within and around cocoa farms in the Dormaa West District of the Brong Ahafo Region of Ghana
Methods	<ul style="list-style-type: none"> • The research was carried out in the Dormaa west area of Ghana, which is located in the western section of the Brong-Ahafo region. • It is one of the country's most important cocoa-producing districts. • Four cocoa-growing villages; Nkrankwanta, Diabaa, Krakrom, and Kwakuanya were chosen at random from the research region. • From December 2014 to February 2015, 64 water samples were obtained from hand dug wells on and near the designated cocoa fields.
DDT level/presence in water sources	<ul style="list-style-type: none"> • An isomer of DDT, p,p'-DDT, was found in 31.6% of the water samples tested, with a mean concentration of $0.04 \pm 0.00 \mu\text{g/l}$ for dry season. • The mean p,p'-DDT concentration measured at distances of 16–30 m was greater than the mean value measured at distances of 0–15 m. • Water samples taken from cocoa farms at distances greater than 30 m (control) revealed no p,p'-DDT concentration.
Type of water source	Hand dug wells
Uses of water source	Drinking water
Sources of water contamination	Runoff from cocoa farms
Human exposure to water source	No mention of human exposure or risk.

E.4. Studies exploring DDT levels in the waterways of Kenya

Author name(s)	Muendo, B. M., Lalah, J. O., Getenga, Z. M (2012)
Article title	“Behavior of pesticide residues in agricultural soil and adjacent River Kuywa sediment and water samples from Nzoia sugarcane belt in Kenya.”
Aim	The aim of the study was to conduct an inventory survey to determine pesticide usage in a sub-catchment of the Nzoia sugarcane belt
Methods	<ul style="list-style-type: none"> • This study was conducted in Nzoia Sugarcane Company Nucleus Estate farms located in Bungoma district in Kenya. • The soil, water, and sediment samples were collected in August 2008 (during a heavy rainstorm) for the first sampling and in December 2008 (during a dry/light rainstorm) for the second sampling. • For water sampling, three composites of water samples were made by pooling several samples taken from the river by grab method. • The grab samples were taken across the river, in 2.5-L amber glass bottles, in the morning and in the evening. • The water samples (1 L each) were then extracted with C18 SPE cartridges.
DDT level/presence in water sources	<ul style="list-style-type: none"> • The concentrations of DDT residues (mean \pm SD) detected in River Kuywa water were p, p’DDT- 1.36 ± 0.13 and 0.17 ± 0.06 (lg/l) in the first sampling in August 2008 (heavy rains) and second sampling in December 2008 during light rain, respectively.
Type of water source	River
Uses of water source	Drinking and recreational use
Sources of water contamination	Run off from sugarcane farms
Human exposure to water source	There is no mention of human exposure/ risk

Author name(s)	Musa, S., Gichuki, J. W., Raburu, P. O., Aura, C. M (2011)
Article title	“Risk assessment for organochlorines and organophosphates pesticide residues in water and Sediments from lower Nyando/Sondu-Miriu river within Lake Victoria Basin, Kenya.”
Aim	The aim of this study was to survey and document pesticide residue levels in the lower Nyando/Sondu-Miriu catchment areas of Lake Victoria, Kenya, during the dry and rainy seasons of 2009.
Methods	<ul style="list-style-type: none"> • This research was carried out in Kenya along the Nyando/Sondu-Miriu river. • In 2009, sampling was carried out at seven different locations in the Nyando Sondu-Miriu Basin between January and March (dry season) and October and December (rainy season). • Organochlorine and organophosphorus pesticide residues, water and sediment samples were analysed for chosen pesticide residues using gas chromatography fitted with Ni63 and CP-SIL 8CB-15m and TSD detectors, respectively.
DDT level/presence in water sources	<ul style="list-style-type: none"> • During the rainy season the Mean concentration (\pmSE) ($\mu\text{g L}^{-1}$) of DDT metabolites were as follows; p,p-DDT (0.09 ± 0.012) ; o,p-DDE (0.09 ± 0.017) and p,p-DDD (0.18 ± 0.035); \sumDDT = $0.36 \pm 0.064 \mu\text{g/L}$ • On the other hand during the dry season the Mean concentration (\pmSE) ($\mu\text{g L}^{-1}$) of DDT metabolites were as follows; p,p-DDT (0.08 ± 0.012) ; p,p' DDE (0.07 ± 0.006) and p,p-DDD (0.14 ± 0.012); \sumDDT = $0.29 \pm 0.003 \mu\text{g/L}$ • In the majority (98%) of the samples, the concentrations of p,p-DDD were significantly greater ($P < 0.05$) than those of p,p-DDT.
Type of water source	River
Uses of water source	Provides domestic, industrial, irrigation and power-generation water and also a productive lake fishery
Sources of water contamination	Contamination by agricultural pesticides and pesticides to control vector-borne diseases.
Human exposure to water source	A human health risk assessment was not done.

E.5. Study exploring DDT levels in the waterways of Mozambique

Author name(s)	Villanueva, C. M., Grau-Pujol, B., Evlampidou, I., Escola, V., Goñi-Irigoyen, F., Kuckelkorn, J., Grummt, T., Arjona, L., Lazaro, B., Etxeandia, A., Ulibarrena, E., Nhacolo, A., Muñoz, J (2021)
Article title	“Chemical and in vitro bioanalytical assessment of drinking water quality in Manhiça, Mozambique.”
Aim	The aim was to conducted an exploratory study in Manhiça district (Mozambique) to evaluate drinking water quality using chemical analyses and cell-based assays.
Methods	<ul style="list-style-type: none"> • The research was carried out in the Manhiça district, a semi-rural area in Maputo province, southern Mozambique, in 2019 • The research sampling locations were from improved sources such as constructed fountains (N = 5), protected boreholes with manual pumps (N = 5), and protected wells (N = 5). Including unimproved water sources corresponded to unprotected wells (N = 5), which constituted 20% of the area's drinking water supply. • On the 19th and 25th of July 2018, trained local fieldworkers collected water samples. • Solid phase extraction (SPE) was used to extract organochlorine, organophosphate, triazine, and phenoxyacid pesticides from water using styrene-divinylbenzene polymeric cartridges for organochlorine, organophosphate, and triazine pesticides and C18 cartridges for phenoxyacid pesticides.
DDT level/presence in water sources	The concentration of DDT metabolites in the drinking water samples were found to be; op'-DDT- 0.012 µg/l and pp'-DDT-0.013 µg/l; ∑DDT = 0.025 µg/l (dry season)
Type of water source	Built fountains, boreholes, and wells.
Uses of water source	Drinking water
Sources of water contamination	DDT runoff from IRS, agricultural activities (sugarcane farming)
Human exposure to water source	A human health risk assessment was not done.

E.6. A Study exploring DDT levels in the waterways of Ethiopia

Author name(s)	Loha, K. M., Lamoree, M., de Boer, J (2020)
Article title	“Pesticide residue levels in vegetables and surface waters at the Central Rift Valley (CRV) of Ethiopia.”
Aim	The aim of the study was to determine pesticide residues in tomato, onion, and water samples from this region.
Methods	<ul style="list-style-type: none"> • Seven pesticides, profenofos, metalaxyl, λ-cyhalothrin, 4,4'-DDT, 4,4'-DDE, and α- and β-endosulfan, were measured in vegetables from 20 locations and surface waters from 12 locations in Ethiopia's Central Rift Valley (CRV). • Water bodies (at the inlets and outlets of lakes), agricultural lands, floriculture effluents, and drinking tap water were collected from four categorized areas in the CRV region. • The samples were taken from the same 12 locations during four sampling campaigns in March, May, and July of 2015, as well as July of 2016. • The water sampling locations were Horankelo River outlet from Lake Langano (HOLL), Horankelo River inlet to Lake Abiata (HILA), Bulbula River Outlet from Lake Ziway (BOLZ), and Bulbula River inlet to Lake Abiata (BILA).
DDT level/presence in water sources	4,4'-DDT and 4,4'-DDE residues were not found in water, the reason being that these compounds have poor water solubility.
Type of water source	Surface water from lakes, agricultural lands, floriculture effluents and drinking tap water.
Uses of water sources	Agricultural purposes and for drinking water.
Sources of water contamination	DDT contamination by IRS
Human exposure to water source	No mention of human exposure/ risk.

E.7. A Study exploring DDT levels in the waterways of Zambia

Author name(s)	Munyinda, N. S., Michelo, C., Sichilongo, K (2015)
Article title	“Linking Environmental Exposure with Public Health: Dichlorodiphenyltrichloroethane Extracted from Soils and Water of Recently Exposed Communities of Selected Locations in Zambia.”
Aim	The aim of the study was to quantify the presence of DDT and its metabolites in the soil and water around communities where it was recently used.
Methods	<ul style="list-style-type: none"> • During July 2012, water samples (14) were obtained from drinking water sources such as shallow wells, open streams, and communal taps; in Chongwe (3), Chawama (7), and Mongu (4). • Because there was no IRS application in Mongu, this area was chosen as the control area among all the three areas. • Water samples (14 each) were obtained from drinking sources and gas chromatography-mass spectrometry was used for the analysis and a revalidated method with limits of detection ranging from 0.034 to 0.04 ppb was used.
DDT level/presence in water sources	<ul style="list-style-type: none"> • DDT was detected in water at six of the fourteen sample locations. • DDT levels over the detection limit were not found in water samples taken from Mongu, the reference location. • In general, the lowest concentration of DDT accounted for 4% of the total DDT, while the greatest concentration, 511 ng/g, was detected around a pit latrine in Chawama Township, accounting for 75% of the total DDT. • Total DDT levels in soils and water were reported to be 100.4 (IQR 90.9–110) and 725.4 ng/L (IQR 540–774.5)-dry season, respectively.
Type of water source	Drinking water sources- shallow wells, open streams, and communal taps.
Uses of water sources	Drinking water
Sources of water contamination.	Runoff from IRS of DDT
Human exposure to water source	A human health risk assessment was not done.

E.8. A Study exploring DDT levels in the waterways of Tanzania

Author name(s)	Hellar-Kihampa, H., De Wael, K., Lugwisha, E., Malarvannan, G., Covaci, A., Van Grieken, R (2013)
Article title	“Spatial monitoring of organohalogen compounds in surface water and sediments of a rural–urban river basin in Tanzania.”
Aim	The aim of this study was to assess the occurrence, levels and spatial distribution patterns of PCBs, OCPs and PBDEs in the Pangani river basin.
Methods	<ul style="list-style-type: none"> • This study included three sample campaigns: one in September–October 2009 during the dry season, one in March–April 2010 during the wet season, and one in January–February 2011 shortly before the rainy season. • Water and sediment samples were taken from twelve different locations at the same time. • There are five stations along the main Pangani River and seven along its tributaries: the Kikuletwa, Kikavu, Ruvu, Mkomazi, and Soni rivers. • Surface water and sediments were collected from the 12 sites and extracted using the liquid–liquid and Soxhlet extraction techniques. • Only OCPs were detected in water samples using GC-ECD.
DDT level/presence in water sources	<ul style="list-style-type: none"> • DDT was found in 58% of water samples. • Concentrations of the p,p'-DDT ranged from 320 to 1300 pg/l and that of p,p'-DDE was from 160 to 1460 pg/l; while their total value (ΣDDT=p,p'-DDT+p,p'-DDE) ranged from 590 to 2030 pg/l (dry season).
Type of water source	Surface water from rivers
Uses of water sources	Used for drinking and other domestic purposes, livestock keeping, hydropower generation and industries.
Sources of water contamination	<ul style="list-style-type: none"> • Agrochemical contamination of surface waters.
Human exposure to water source	No mention of human exposure/ risk, but the DDT concentrations were far below the WHO guidelines for drinking water quality.

E.9. Studies exploring DDT levels in the waterways of Egypt

Author name(s)	Dahshan, H., Megahed, A. M., Abd-Elall, A. M., Abd-El-Kader, M. A., Nabawy, E., Elbana, M. H (2016)
Article title	“Monitoring of pesticides water pollution- The Egyptian Nile River.”
Aim	The study was conducted to obtain a large scale monitoring data on spatial distribution of selected organochlorine and organophosphorus pesticides in water samples collected at 20 sampling sites along the River Nile stream and the major delta lakes of Egypt.
Methods	<ul style="list-style-type: none"> • A large-scale monitoring study of organochlorine and organophosphorus residual levels in water samples collected at 20 sampling locations along the Nile River in Egypt was carried out. • During the summer of 2013, 60 water samples were taken from River Nile sampling locations (3 samples each). • The APHA-recommended liquid-liquid extraction method was utilized, and the water sample was extracted twice. • Pesticides were quantified at the Residue Analysis Department, Central Agri. Pesticides Lab, Dokki, Egypt, using an Agilent gas chromatograph 6890 combined with an Agilent HP-5MS.
DDT level/presence in water sources	<ul style="list-style-type: none"> • The mean concentrations for DDT metabolites were; p,p'-DDD: 1.209 µg/l (In Fraskour-Damietta), p,p'-DDT: 0.95 µg/l (Monofea) and 2.268 µg/l (Fraskour-Damietta), p,p'-DDE: 0.21 µg/l (Alwasta-Beni Swelf) and 0.98 µg/l (Monofea). • ΣDDT 5.617 µg/l (dry season)
Type of water source	River streams
Uses of water source	The river is the main source for drinking water for about 90 million citizens.
Sources of water contamination	Major agricultural and industrial activities
Human exposure to water source	A human health risk assessment was not done.

Author name(s)	Kamel, E., Moussa, S., Abonorag, M. A., Konuk, M (2015)
Article title	“Occurrence and possible fate of organochlorine pesticide residues at Manzala Lake in Egypt as a model study.”
Aim	The study aims to assess the degree of contamination and to calculate the possible half-life of OCP compounds in water
Methods	<ul style="list-style-type: none"> • The persistence of OCPs at Manzala Lake in Egypt was investigated in this study. • The areas of El-Gamel, El-Kowar, ElRasoah, and Janb El-Timsah were examined. • For sampling, 2.5 liters of water were collected at a depth of 50 cm from the water's surface and stored in 3-liter glass bottles. • Pesticide residues in water samples were extracted using APHA-recommended procedures.
DDT level/presence in water sources	<ul style="list-style-type: none"> • DDT (3.23±0.307)- dry season, (3.359±0.521)- wet season was only deducted in the water samples from one area out of the four (El-Kowar region) during October and March, respectively.
Type of water source	Lake
Uses of water source	The most important natural resource for fish production in Egypt. It provides more than 7 % of the country's total fish production.
Sources of water contamination	Main meeting point of several polluted water resources
Human exposure to water source	No mention of human risk/ exposure.

E.10. Studies exploring DDT levels in the waterways of Morocco

Author name(s)	Berni, I., Menouni, A., El Ghazi, I., Godderis, L., Duca, R., El Jaafari, S (2021)
Article title	“Health and ecological risk assessment based on pesticide monitoring in Saïss plain (Morocco) groundwater.”
Aim	The present study aimed to thoroughly monitor the groundwater in the Saïss plain area during the summer of 2017 and the winter of 2018 using POCIS and evaluate possible pollution due to pesticides and their degradation products, and assess the ecological and human health risks (for infants, children, and adults) due to the above pollution.
Methods	<ul style="list-style-type: none"> • This research was carried out in the Saïss Plain, which is located in north-central Morocco and is made up of 35 nations, 12 of which have the most intense agricultural operations due to the existence of groundwater aquifers and fertile soils. • Pesticides were measured in Saïss plain groundwater (Morocco) utilizing polar organic chemical integrative samplers throughout the summer of 2017 and the winter of 2018. • For 14 to 20 days, two types of passive samplers were placed in 22 conventional wells and subjected to solid-phase extraction. • Gas chromatography-mass spectrometry and liquid chromatography-tandem mass spectrometry were used to analyse the extracts, and 27 pesticides were identified in total.
DDT level/presence in water sources	<ul style="list-style-type: none"> • Maximum individual DDT concentrations were reported to be 36.1 ng/l during the summer period, and 16.62 ng/l during the winter period, which was one of the highest concentrations observed for this season. • Summer mean (dry season) \sumDDT = 0.0564 µg/l • Winter mean (wet season) \sumDDT = 0.03046 µg/l
Type of water source	Ground water
Uses of water source	Drinking water and agricultural purposes
Sources of water contamination	<ul style="list-style-type: none"> • Agricultural activities. • And technical DDT use.
Human exposure to water source	<ul style="list-style-type: none"> • The carcinogenic risk of DDT in infants, children and adults was; (1.8×10^{-5}); (1.6×10^{-6}) and (2.4×10^{-7}), respectively. • And for DDE in infants, children and adults was; (1.8×10^{-5}); (1.4×10^{-6}) and (2.2×10^{-7}), respectively.

Author name(s)	Lakhlalki, H., Jayed, M., Benbrahim, S., Rharbi, N., Benhra, A., Moutaki, B., Maanan, M (2020)
Article title	“Assessment of contamination by organochlorine pesticides and polychlorinated biphenyl’s from Oualidia lagoon water (Morocco).”
Aim	The aim of the study was to assess the contamination degree of Oualidia lagoon surface water by organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs) through the monitoring of 13 compounds from the Stockholm Convention black list.
Methods	<ul style="list-style-type: none"> • The contamination degree of Oualidia lagoon surface water by organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs) was assessed in this study by monitoring 13 chemicals from the Stockholm Convention blacklist. • The research was carried out in the Oualidia lagoon, a Moroccan environment located between El Jadida and Safi. • From May 2015 to April 2016, surface water samples were collected weekly from 5 locations to guarantee geographic coverage of the lagoon. These sample locations were chosen because of their aquaculture and agricultural potential. • 1 L of surface water was collected at each site and at low tide in a clean shaded glass container. • Furthermore, these substances were analyzed using liquid-liquid extractions followed by a gas chromatographic method with an electron capture detector (GC-ECD).
DDT level/presence in water sources	p,p' DDT was found to be the most dominant compound with a mean value of 0.000023 mg/l, throughout all seasons.
Type of water source	Lagoon water
Uses of water source	Oyster and cereal farming
Sources of water contamination	<ul style="list-style-type: none"> • Receives seawater, • Exposed to agricultural areas, salt marsh, pasture land, and urban areas due to land use, • Meeting point for runoff water and infiltrations through septic tanks that drain pollutants and effluents from oyster farming.
Human exposure to water source	No mention of human exposure or risk.