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Status of persistent organic pollutants in Ethiopia

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Over the years, the chemical market has shown significant growth, but the hazardous impact of chemical use and disposal on the environment and human health is a growing concern. Persistent organic pollutants (POPs) are among the most dangerous chemicals with widespread effects on the environment and living organisms, including humans. This study aimed to assess the current status of POP management and regulatory infrastructure in Ethiopia by collecting information from stakeholders responsible for recording the import, export, use, management, and regulation of POPs both in government and private sectors. Additionally, a comprehensive literature review was conducted using Boolean operators from international databases and libraries. The results indicated that Ethiopia banned the import of pesticides listed under Annex A (i.e., those to be eliminated), except endosulfan, which was imported at a quantity of 199,767 kg lt⁻¹ from 2011 to 2015. There are 2,435 PCB-containing transformers in Ethiopia, of which 2,242 (92%) are currently in use. These transformers and capacitors contain 1,031,661 kg and 1,255 kg of dielectric fluids, respectively. As for Annex B POPs (i.e., those to be restricted), there are between 928,509 kg and 1,383,095 kg of active and obsolete dichlorodiphenyltrichloroethane found in different stores across the country. Ethiopia imported approximately 337,000 kg of products containing perfluorooctane sulfonic acid from 2000 to 2020, with an annual average of 16,850 kg of photographic film, paper, and plates. POPs were also detected in different environmental matrices (soil, waterbodies, sediments, food items, and air) as well as human blood. Despite these findings, regulation and management of POP waste and stockpiles are largely inadequate in Ethiopia. Therefore, it is crucial to improve the monitoring, management, and regulation of POPs in the country. This could be achieved by strengthening the collaboration among different regulatory bodies, harmonizing the fragmented laws on POP management and control, and building institutional capacity.

KEYWORDS

persistent organic pollutant, national implementation plan, Ethiopia, Stockholm Convention, chemicals

1 Introduction

Persistent organic pollutants (POPs) refer to a group of chemicals, including industrial chemicals, pesticides, and unintentional by-products, that share common characteristics, such as environmental persistence (Aljerf and AlMasri, 2018; Sathishkumar et al., 2021), bioaccumulation (Weltmeyer et al., 2021), and long-range transport potential. These

chemicals are ubiquitous in the environment (Scheringer, 2009; Hageman et al., 2015; Kallenborn et al., 2015), and exposure to them has been linked to significant changes in the human gut microbiome, resulting in toxicity (Popli et al., 2022) as well as an increased risk of type 2 diabetes and hypertension (Hernández-Mariano et al., 2022). Prenatal exposure to POPs has also been associated with an increased risk of developing gestational diabetes in pregnant women (Zhang et al., 2018) and causing cardiometabolic effects on offspring not only during infancy but also up to adolescence (Güil-Oumrait et al., 2021).

The negotiation process for the Stockholm Convention, the main multilateral environmental agreement regulating POPs, started in the 1990s, and it was eventually adopted in 2001, before being enforced in 2004 (Scheringer, 2009, Secretariat of the Stockholm; Convention, 2019a). The convention initially targeted 12 POPs, known as the 'dirty dozen,' which included polychlorinated biphenyls (PCBs) and some organochlorine pesticides (OCPs) (Secretariat of the Stockholm Convention, 2019b). However, over the years, the list of restricted compounds has grown (Secretariat of the Stockholm Convention, 2022a), with six additional compounds (Dechlorane Plus, methoxychlor, UV-328, chlorpyrifos, chlorinated paraffins, and long-chain perfluorocarboxylic acids, their salts, and related compounds (LC-PFCAs)) currently under review for inclusion to the list (Secretariat of the Stockholm Convention, 2022b). The Stockholm Convention categorizes POPs into different groups, such as Annex A, B, and C, and mandates that parties take measures to eliminate and restrict the production and use of chemicals listed under Annex A and Annex B, respectively. Annex C chemicals are generally considered unintentional by-products.

The Stockholm Convention has 152 signatories and 186 parties, including Ethiopia, which submitted its first National Implementation Plan (NIP) on POPs in 2006 (EMEFCC, 2006). However, the plan has not been updated despite additional POPs being included in the convention, which puts Ethiopia behind other countries in the region (e.g., Kenya, Burundi, Tanzania, and Seychelles) that have updated their NIPs. Several reviews have been conducted on the POP situation in different countries, focusing on research trends and regulation (Sheriff et al., 2021), environmental levels and human exposure (Minh et al., 2008; Mazlan et al., 2017; Bruce-Vanderpuije et al., 2019; Helou et al., 2019; Olisah et al., 2021; Rezania et al., 2022), sources (Olishah et al., 2021), and levels in fish and food (Mazlan et al., 2017; Uzomah et al., 2021). However, recent information on the POP situation in Ethiopia is lacking. This study seeks to address this gap by providing a comprehensive assessment of the status, management, and regulatory infrastructure (legal, institutional, administrative, and technical) of POPs in Ethiopia. The outcome can be used to develop evidence-based policies and strategies to reduce POP exposure and contamination in Ethiopia.

2 Methodology

2.1 Data collection

The study used two methods of data collection. First, a checklist was developed to obtain information on the use, import, export, releases, alternative future use of POPs, institutional collaboration,

and management of POP stockpiles. The data were collected from organizations responsible for recording the import, export, use, management, and regulation of POPs both in private and government sectors. Table 1 presents the list of these organizations and the nature of the information collected from each.

Second, a comprehensive literature review on POPs in Ethiopia was conducted. Scopus, Science Direct, Web of Science, Google Scholar, and PubMed were searched using Boolean operators and keywords, such as Stockholm Convention, National Implementation Plan, and Ethiopia, to locate published articles. The search was conducted without any time restrictions to find relevant studies on POPs. The review included studies conducted in Ethiopia that reported on the level of POPs in environmental media, as well as articles published in scientific journals and gray literature. All papers and reports were critically evaluated based on their title, abstract, and full-text, and only full-text articles written in English were considered.

2.2 Data analysis

The data were transferred to and analyzed using STATA software (StataCorp. 2021. Stata Statistical Software: Release 17. College Station, TX: StataCorp LLC). The STATA software was also used to generate maps that illustrate the storage and regional distribution of chemicals.

3 Results and discussion

3.1 Annex A pesticides

Based on an inventory conducted by the Ethiopian Revenue and Customs Authority since 2000, Ethiopia has not yet produced any pesticide listed under Annex A. Moreover, with the exception of endosulfan, the country has not imported any old or new Annex A pesticide. Therefore, this study solely focuses on endosulfan, which is utilized in high quantities for controlling cotton pests in Ethiopia's agricultural sector. Table 2 shows that approximately 200,000 L of endosulfan were imported between 2015 and 2020, although there are no data available for 2019. Farming activities may lead to the direct release of endosulfan to the environment. Apart from endosulfan, the first NIP in 2006 identified four types of obsolete Annex A pesticides: aldrin, dieldrin, heptachlor, and chlordane, with respective quantities of 2,159, 2,822, 7,043, and 2,591 kg Lt⁻¹ (EMEFCC, 2006). In the northern region of Ethiopia, stockpiles of aldrin, heptachlor, and dieldrin were 1,398, 1,523, and 621 kg, respectively (Haylamicheal and Dalvie, 2009b; Debela et al., 2020b).

3.2 Annex A PCBs

The data provided by the Ethiopian Electric Utility reveal that there are 2,435 transformers in Ethiopia that contain PCBs, out of which 2,242 are currently in use. In contrast, the 2006 NIP documented 2,505 PCBs containing electric transformers, and nearly 2,415 of them were in use (EMEFCC, 2006). The difference in these two reports (-70 in the first) could be due to

TABLE 1 List of organizations and the nature of the information collected on POPs in Ethiopia.

S. no.	Name of organizations	Information obtained
1	• Environmental Protection Agency (EPA)	Regulation of all POPs, including unintentional by-products
	• Ethiopian Chemical Institute	
2	• Ministry of Agriculture	Supply, distribution, and marketing of agricultural inputs and the proper administration and control of pesticides
3	• Ministry of Health	Usage of some POPs (e.g., DDT) for malaria control and other POPs contained in medical equipment
4	• Ministry of Trade and Regional Integration	Transportation, provision, and control of commercial registration and licensing of POPs
	• Ethiopian Revenue and Customs Authority	
5	• Ministry of Water and Energy	Information on various industrial POPs, such as PCBs, perfluorooctane sulfonic acid (PFOS), polybrominated diphenyl ethers (PBDEs), and perfluorooctanesulfonyl fluoride (PFOSF), which are used in a range of industries, including electric utilities, plastics and rubber products, foams, aviation, photography, sealants and adhesives, metal plating, and leather production
	• Ethiopian Electric Utility	
	• Ministry of Industry	
	• Ethiopian Airlines	
	• Ethiopian Leather Development Institute	

TABLE 2 Imported quantities of endosulfan (trade name—Thionex) from 2015 to 2020 in Ethiopia (source: the Ethiopia Revenues and Customs Authority).

Trade name	Purpose	Quantity (liters)	Year of import
Thionex 35%EC	For farm use	55	2015
Thiodan 25%ULV	Commercial	20,000	2015
Thionex 35%EC	Commercial	9,240	2015
Thionex 35%EC	Commercial	15,200	2016
Thionex 35%EC	For farm use	160	2017
Thionex Technical	For formulation	120,000	2017
Thionex 35%EC	Commercial	8,316	2017
Thionex 35%EC	Commercial	17,556	2018
Thionex 35%EC	Commercial	9,240	2020

the initial inventory’s incompleteness in terms of assessing suspected locations. The total quantities of suspected PCB-containing dielectric fluids in these transformers and capacitors are 1,031,661 kg and 1,255 kg, respectively. The 2006 NIP reported that the weight of PCB-containing dielectric fluids was 1,181,667 kg and 1,255 kg for transformers and capacitors, respectively (EMEFCC, 2006). For capacitors, the weight reported in 2006 and in the current assessment remains unchanged. The slight variation in the weight of transformer dielectric fluid implies that the responsible bodies either did not update the data or the fluids were not disposed-off due to limited capacity. It is also essential to note that the time/year when the Ethiopian Electric Utility updated its PCB inventory for this study remains unclear.

Western Ethiopia has the highest number of PCB-containing transformers, with 497, followed by the southern Addis Ababa Region, with 357 (Figure 1 and Supplementary Table S1). This is

in contrast to the 2006 NIP report, which reported the highest number of PCB-containing transformers in the Central Region as 674, followed by 309 in Western Ethiopia (EMEFCC, 2006). The Ethiopian Electric Utility reports that some PCB-containing transformers are currently in use and are kept in workshops for maintenance, while others have been discarded. All PCB-containing transformers were manufactured before 1989, and there is a workshop for PCB transformer maintenance in the Central Region.

The Ethiopian EPA has identified three current PCB hotspot areas across the country: Gofa central warehouse, Kotobe auxiliary maintenance workshop, and METEC-EPEI (a newly established transformer refurbishing and manufacturing factory). Gofa central warehouse was the only hotspot identified in the 2006 NIP (EMEFCC, 2006). Discarded transformers, suspected to contain PCB oil, were stored in steel tankers at the Kotobe maintenance workshop (Debela et al., 2020a; Debela et al., 2021). Transformers, capacitors, and PCB-suspected dielectric fluids and oil are located in highly populated areas in the cities. These materials are stored in an unlocked fenced area. According to the information obtained from the Ethiopian Electric Utility, 11,232 L of dielectric fluid and oil were sold to a lime-producing factory in 2016, which used it as an energy source for lime processing.

3.3 Annex B pesticides

DDT was formulated in Ethiopia by the Adami Tulu Pesticide Processing Share Company for the purpose of controlling vector-borne diseases, such as malaria. However, there are no available data on the importation and exportation of DDT. A previous assessment reported 160, 573 Kg Lt⁻¹ active and 55, 720 Kg Lt⁻¹ obsolete DDT in different storage sites of the country (EMEFCC, 2006) (Figure 2, Figure 3). According to the Ministry of Agriculture, there are a total of 1,383,095 kg of both active and obsolete DDT in Ethiopia, whereas data from the Ethiopian EPA indicate that only 928,509.3 kg are present (Supplementary Table S2). It could be

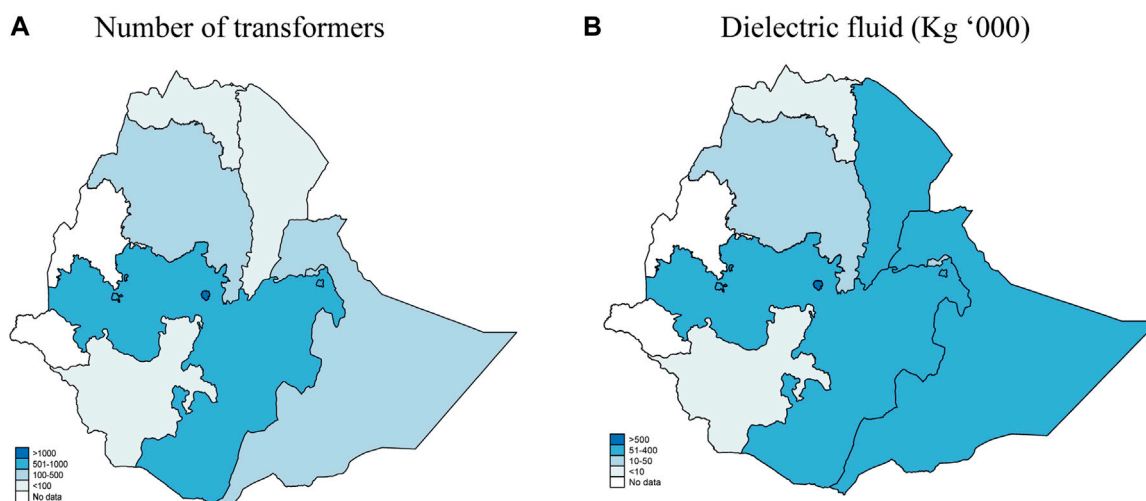


FIGURE 1 (A) Number of transformers and (B) dielectric fluid (Kg '000) in different regions of Ethiopia (detailed reports are indicated in Supplementary Table S1; source: the Ethiopian EPA and Ethiopian Electric Utility).

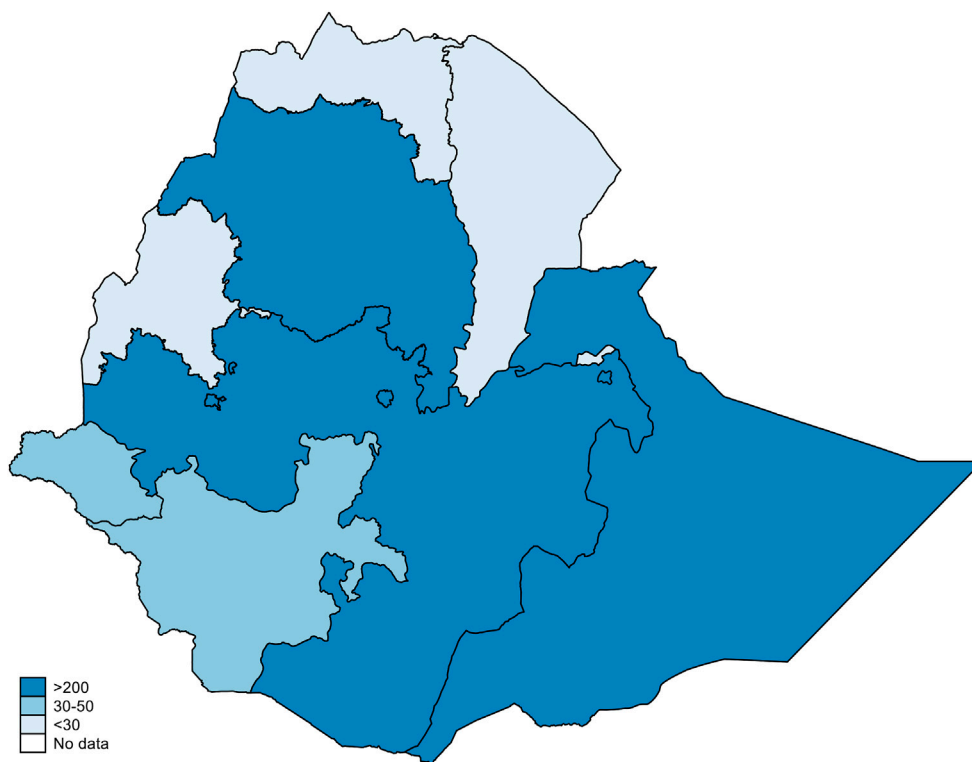


FIGURE 2 DDT amount (Kg '000) in different regions of Ethiopia (detailed reports are indicated in Supplementary Table S2; source: the Ethiopian EPA).

seen that the DDT data provided by these two government institutions that are in charge of pesticides were not the same. This discrepancy highlights the need for greater collaboration

among government ministries, departments, and agencies. The Adami Tulu Pesticide Processing Share Company warehouse currently stores 454,586 kg of DDT, and there are approximately

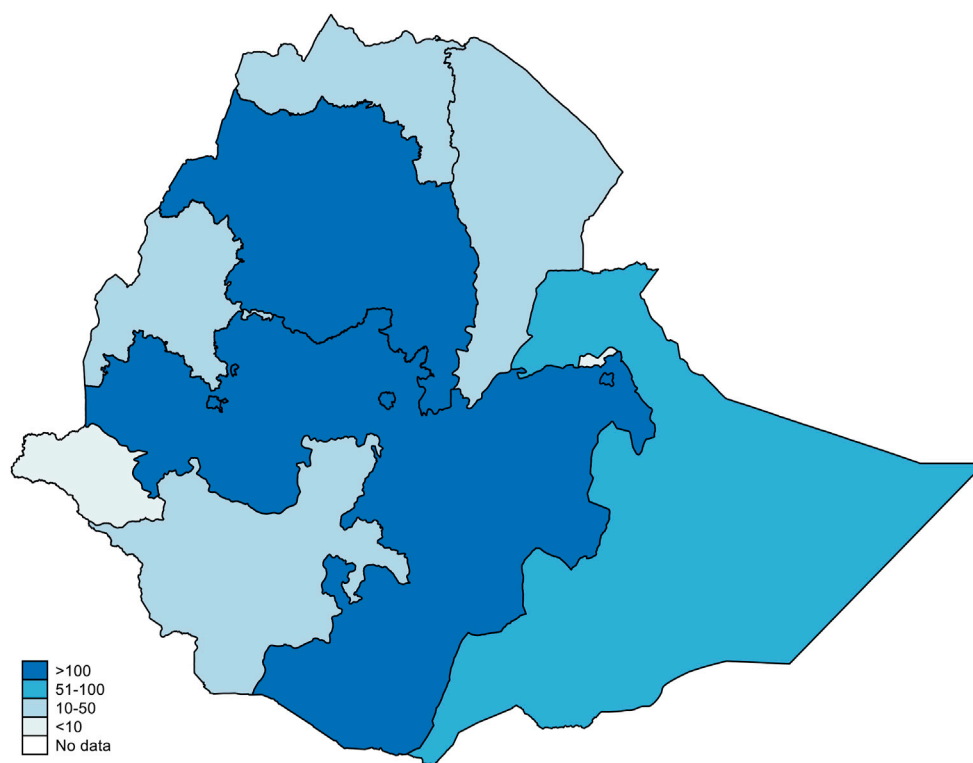


FIGURE 3
Number of DDT stores in different regions of Ethiopia (detailed reports are indicated in [Supplementary Table S1](#); source: the Ethiopian EPA).

460 sites suspected to be contaminated with DDT. Production of DDT for disease vector control was permitted under the Stockholm Convention (UNEP, 1997); however, studies have shown that disease vectors in Ethiopia are developing resistance to DDT (Alemayehu et al., 2017; Demissew et al., 2022). As a result, the Ministry of Health has been using alternative non-POP chemicals, such as piperonyl butoxide, pyrethroid, and carbamates, since 2018 (Gari and Lindtjorn, 2018). Despite being officially discontinued for vector control, there are reports of smallholder farmers purchasing DDT from the illegal market for other purposes. This has resulted in the unintentional release of DDT into the environment due to improper storage and illegal use (Mekonen et al., 2017; Afata et al., 2022; Endalew et al., 2022).

3.4 Annex B perfluorooctane sulfonic acid

The information on the production and use of PFOS and its related substances and articles suspected for PFOS were collected from Ethiopian Airlines, the Ministry of Trade and Regional Integration, the Ministry of Industry, and the Ethiopia Chemical Institute. PFOS is used in different sectors, including photo imaging, metal plating, mining, plastic and rubber products, textile, leather, synthetic carpet, pulp and paper, paints, varnishes, electric and electronic parts, firefighting foam, hydraulic fluids, and others. From 2000 to 2020, Ethiopia imported approximately 337,000 kg of PFOS-containing products, including photographic film, paper,

and plates, with an annual average imported quantity of 16,850 kg. According to the Ethiopian EPA, emission of PFOS from these sectors is 2.2 kg per year ([Supplementary Table S1](#) and [Supplementary Table S2](#)). METECH Engineering, the Ethiopian Air Force, and Ethiopian Airlines are among the large companies that operate their own maintenance workshops and utilize PFOS for plating purposes. However, the Ministry of Mines, Petroleum, and Natural Gas has reported that there is no mining industry in Ethiopia that uses PFOS. Similarly, the respective industry bodies of plastic and rubber production, textile, and leather manufacturing have reported that they do not use PFOS or PFOS-containing products in their operations.

Other potential sources of PFOS in Ethiopia may include imported carpets and pulp and paper production. To estimate the potential use of PFOS in imported carpets, data on the total amount of imported synthetic carpets were collected. Between 2000 and 2020, Ethiopia imported 105,764 kg of synthetic carpets, with an average annual import quantity of 5,288 kg. This indicates a potential consumption of 3.3–33.6 kg of PFOS per year, assuming that all imported carpets contain PFOS. However, the pulping industry in Ethiopia is still in its infancy and not yet at the stage of using PFOS chemicals. Most of the paper used in Ethiopia is imported, and some paper plants use recycled paper and cartons for pulp production. Packed food materials are also imported, which may contain PFOS. These packing materials are typically disposed-off as garbage in open fields and dump sites, which

can lead to the entry of PFOS-containing materials into the environment.

Although Ethiopia's aviation hydraulic fluid and firefighting foam industries are not using PFOS, they may use PFOS derivative chemicals. For example, hydraulic fluid Skydrol LD4 contains a minimal amount of PFOS. However, these industries do not have any stockpile of PFOS-containing waste under their control. As municipal solid waste in Ethiopia is collected and dumped without segregation (Akele and Tarekegn, 2017; Amare et al., 2022; Lewoyehu et al., 2022) and industries discharge their wastewater with little or no treatment to the surrounding river, PFOS-containing waste materials from industries are likely to cause environmental contamination (Ahrens et al., 2016).

3.5 Polybrominated diphenyl ethers

Ethiopia has imported PBDEs through electrical and electronic equipment and in-vehicle products. The country has experienced a rapid transformation in Information and Communication Technology (ICT) in recent years, resulting in the importation of computers, mobile phones, and TV sets from developed countries. This has contributed to the increasing amount of electronic waste. There is only one TV assembly company in Ethiopia, and it uses PBDEs.

3.6 Annex C POPs

There are no reliable data on the status of other POPs in Ethiopia. However, the Ethiopian EPA believes that there is unintentional production of Annex C POP chemicals from different categories of sources, such as uncontrolled combustion process of waste incineration, metal and mineral production, transport, power generation, and household heating with biomass and charcoal. During data collection, we found that the level of awareness concerning unintentional POPs among government officials was very low.

3.7 POP disposal facilities in Ethiopia

In Ethiopia, there is no dedicated chemical disposal facility, potentially leading to the accumulation of chemicals in the county. Except for POP pesticides, there have been no efforts to dispose-off other POP chemicals at the time of this assessment. In 2015, various donors and/or partners disposed-off 1,502, 1,093, and 450 tons of chemicals containing 25%, 10%, and 2% POP pesticides, respectively. Furthermore, the United States Agency for International Development (USAID) recently disposed-off 85 tons of DDT as well as 15 tons of DDT-contaminated packing cartons. The Enkoken company in Finland disposed-off 1,511 tons of obsolete pesticides from 220 stores in collaboration with the Food and Agriculture Organization (FAO) and the Ministry of Agriculture between 2000 and 2003 (Haylamicheal and Dalvie, 2009b; Debela et al., 2020b). In addition, Veolia Environmental Services in England removed 1,000 tons of obsolete pesticides during the second phase from 2006 to 2007 (Haylamicheal and Dalvie,

2009a). In 2015, the African Stockpile Project and USAID also disposed-off 3,050,000 kg of DDT.

3.8 POP-contaminated sites in Ethiopia

In the current study, there are no data and figures on POP-contaminated sites in Ethiopia. In the 2006 NIP, 220 contaminated stores and sites were identified across the country. It consisted of 178 contaminated stores (where 41 stores were contaminated by spilled chemicals from the store), 23 burial sites, and 19 open-container stores (EMEFCC, 2006), with the Oromia region having the highest number (102) of contaminated sites.

3.9 Monitoring of POPs in environmental matrices and human blood

This section presents POP concentrations in different environmental matrices, such as soil (Table 3), waterbodies (Table 4), sediments (Table 5), food items (Table 6), and air (Table 7), as well as human blood (Table 8), from different locations in Ethiopia.

3.9.1 Soil

Soil from agricultural land, urban areas, and industrial areas is identified as a major source of organic pollutants, including pesticides (DDT, aldrin, dieldrin, heptachlor, and others) and PCBs (dioxin and non-dioxin) (Table 3) in Ethiopia. A study performed in a transformer workshop and dumpsite in Addis Ababa industrial soil found that PCB levels in the soil ranged from 1.027 to 4.862 mg kg⁻¹ and dioxin-like (DL) Σ12PCBs ranged from 1.6036 to 0.56128 mg kg⁻¹, while non-dioxin-like (NDL) Σ6PCBs ranged from 0.166 to 4.5 mg kg⁻¹ (Debela et al., 2020a). In another study, slight PCB levels in the urban soil of Addis Ababa Σ16PCB ranged from 0.4 to 18.5 μg kg⁻¹ (Prasse et al., 2012).

In the upper Awash agricultural soil, different POP pesticides, such as endosulfan derivative, aldrin, dieldrin, DDT derivative, and heptachlor, were also detected (Westbom et al., 2008). The highest levels of endosulfan were found in a concentration range of 4.6–28,900 ng g⁻¹. The concentration of PCBs in an urban area is lower than in an industrial area. For the past 40 years, the industrial area has been used for PCB maintenance and disposal. Furthermore, in Ethiopia, eight regions have been identified as potentially contaminated by PCBs, and in all areas, PCB-containing equipment is kept in open filled storage (EMEFCC, 2006).

3.9.2 Water

Four studies investigating the presence of POPs in lakes and rivers were identified. POPs, such as organochlorine pesticides, PCBs, polyfluoroalkyl substances (PFASs), and PFOS, have been found in the Akaki River, Lake Awassa (Hawassa), Lake Tana, and Lake Ziway in recent studies (Table 4). In the Akaki River, the concentrations of ΣDDTs were in the range of 5.33–30.58 ng L⁻¹, which is higher than other POP chemicals (PCBs, PFASs, and PFOS) detected in the lakes of Tana, Ziway, and Awassa. The Akaki River is a river that drains across the capital city (Addis Ababa) and has the potential to be contaminated by different pollutants (Kassegne et al.,

TABLE 3 Concentration of POP chemicals detected in soil.

Location	Type of POPs	Extraction type	Instrument	Concentration	References
Upper Awash agricultural soil	a-Endosulfan	SPLE	GC-ECD	4.6–28900 ng g ⁻¹	Westbom et al. (2008)
	b-Endosulfan			1.8–25900 ng g ⁻¹	
	Endosulfan sulfate			1.2–1,140 ng g ⁻¹	
	Aldrin			Nd–3.8 ng g ⁻¹	
	Dieldrin			Nd–2.4 ng g ⁻¹	
	Heptachlor			Nd–1.8 ng g ⁻¹	
	α-HCH			Nd–5.5 ng g ⁻¹	
	β-HCH			Nd–0.9 ng g ⁻¹	
	γ-HCH			Nd–3.3 ng g ⁻¹	
	p,p'-DDT			0.7–4.9 ng g ⁻¹	
	p,p'-DDE			20–225 ng g ⁻¹	
Addis Ababa	Σ6PCBs	ASE	GC-MS	0.3–7.5 μg kg ⁻¹	Prasse et al. (2012)
	Σ16PCBs			177–1,640 μg kg ⁻¹	
Transformer area	Σ6PCBs	PLE	GC-MS	403–4050a μg kg ⁻¹	Debela et al. (2020a)
	Σ12PCBs			561–1,186 μg kg ⁻¹	
	Σ7PCBs			1,027–486 μg kg ⁻¹	

Nd, not detected; SPLE, solid-phase liquid extraction; PLE, pressurized liquid extraction; ASE, accelerated solvent extraction; GC-MS, gas chromatography–mass spectrometry; GC-ECD, gas chromatography electron capture detector.

TABLE 4 Concentration of POP chemicals detected in Ethiopian waterbodies.

Location	Type of POPs	Extraction type	Instrument	Concentration	References
Akaki Catchment River	ΣDDT	LLSE	GC-MS	5.33–30.58 ng L ⁻¹ (mean 11.39 ng L ⁻¹).	Kassegne et al. (2020)
	Lindane			15.4 ± 0.25 ng L ⁻¹	
	Dieldrin			4.85 ± 0.007 ng L ⁻¹	
Lake Ziway	Endosulfun	EPE	GC-ECD	.095–59 ug L ⁻¹	Teklu et al. (2018)
Lake Tana	PFAS	SLE	HPLC	0.073–5.6 ng L ⁻¹	Ahrens et al. (2016)
Lake Awassa	PFOA	SPE	UPLC-MS/MS	6.24–10.7 ng L ⁻¹	Melake et al. (2022)

LLSE, liquid–liquid and Soxhlet extraction; EPE, eichloromethane and petroleum ether; SLE, solid–liquid extraction; SPE, solid-phase extraction; GC-MS, gas chromatography–mass spectrometry; GC-ECD, gas chromatography electron capture detector; HPLC, high-performance liquid chromatography; UPLC-MS/MS, ultra-high-performance liquid chromatography–tandem mass spectrometry.

2020). The detection of POPs in waterbodies may eventually lead to human exposure through different routes.

3.9.3 Sediment

Water is one of the primary transport channels for substances with hydrophilic functions, such as POPs, whereas sediments typically serve as repositories for these substances because they also have hydrophobic functionalities (Ssebugere et al., 2020). Most POPs have been detected in sediments. According to Kassegne et al. (2020), DDT was the most prevalent pesticide found in all sediment samples collected from the Akaki Catchment River and Aba Samuel (Table 5). DDT concentrations ranged from 1.91 to 1,076.73 g kg⁻¹. In addition, other OCPs were detected in this study area. PCBs have been detected in Addis Ababa urban sediment (Σ16 PCBs ranged

from 712 to 3,040 mg kg⁻¹), which is higher than studies conducted by other authors in the sediment of the upper Awash and Lake Tana (Table 4). PCDD and PCDF have also been detected in Lake Tana and the Koka Reservoir. Sediment from Lake Tana has higher concentrations of both PCDD and PCDF than that from Koka Reservoir. PFOA was also detected in Awassa Lake and ranged from 0.1 to 0.6 ng g⁻¹ dw (Ahrens et al., 2016).

3.9.4 Air

The literature on the levels of POPs in the air in Ethiopia is very limited. To date, only two studies have investigated the occurrence of organochlorines in the air. However, the available data show that the levels of POP chemicals are low and vary widely among the two identified study locations. In Ziway, three POPs, namely, heptachlor, DDT, and

TABLE 5 Concentration of POP chemicals detected in sediments.

Location	Type of POPs	Extraction type	Instrument	Concentration	References
Akaki Catchment River and Aba Samuel	ΣDDT	LLSE	GC-MS	1.91–1,076.7 μg kg ⁻¹	Kassegne et al. (2020)
	Lindane			120.51 μg kg ⁻¹	
	Dieldrin			78.56 ± 0.14 μg kg ⁻¹	
	Abendosulfan			127.7 ± 0.01 μg kg ⁻¹	
	Heptachlor			12.65 ± 0.01 μg kg ⁻¹	
	ΣPCBs			Nd–63.76 μg kg ⁻¹	
Addis Ababa	Σ6PCBs	ASE	GC-MS	3.4–13.7 mg kg ⁻¹	Prasse et al. (2012)
	Σ16PCBs			712–3,040 mg kg ⁻¹	
Lake Tana	PFAS	SLE	HPLC	0.22–0.55 ng g ⁻¹	Ahrens et al. (2016)
Upper Awash	Σ 7PCB	Soxhlet	GC-ECD/MS	0.85–26.56 ng g ⁻¹	Dirbaba et al. (2018)
	Σ 7PBDEs			3.71–18.95 ng g ⁻¹	
	Σ 8DDT			1.99–139.68 ng g ⁻¹	
Lake Awassa	PFOA	SPE	UPLC-MS/MS	0.1–0.6 ng g ⁻¹ dw	Melake et al. (2022)
Lake Awassa	PCDD	ASE	HRGC-HRMS	120.8 ± 17.7 pg g ⁻¹	Urbaniak and Zalewski (2011)
	PCDF			149.56 ± 9.79 pg g ⁻¹	
Koka Reservoir	PCDD			37.29 ± 9.80 pg g ⁻¹	
	PCDF			25.88 ± 3.01 pg g ⁻¹	
Lake Tana	PCBs	PLe	GC-MS	10.8–14.4 ng g ⁻¹	Zebeaman and Schmid (2019)

LLSE, liquid-liquid and Soxhlet extraction; SLE, solid-liquid extraction; SPE, solid-phase extraction; ASE, accelerated solvent extraction; PLe, pressurized liquid extraction; GC-MS, gas chromatography-mass spectrometry; GC-ECD, gas chromatography electron capture detector; HPLC, high-performance liquid chromatography; UPLC-MS/MS, ultra-high-performance liquid chromatography-tandem mass spectrometry; HRGC-HRMS, capillary column high-resolution gas chromatography-high-resolution mass spectrometry.

TABLE 6 Concentration of POP chemical detected in the air of the towns Ziway and Assela.

Place	Type of POPs	Extraction type	Instrument	Concentration	References
Ziway (City)	Heptachlor	SSE	GM-MS	151.1 mg m ⁻³	Mesfin (2019)
	DDT			19.61 mg m ⁻³	
	Benzene hexachloride			4.64 mg m ⁻³	
Assella	PCB	SE	GC-MS	1.2–2.5 ng m ⁻³	UNEP (1997)
	Adrin		GC-APCI-MS	LOQ–1.4 ng m ⁻³	
	Dieldrin		GC-APCI-MS	LOQ–1.4 ng m ⁻³	
	DDT		GC-MS	61.5–152.4 ng m ⁻³	
	HCB		GC-MS	2.8–4.1 ng m ⁻³	
	PCDDs		GC-HRMS	80–102.2 ng m ⁻³	
	PCDFs		GC-HRMS	205.1–286.3 ng m ⁻³	

SSE, Soxhlet solvent extraction; SE, Soxhlet extraction; LOQ, limit of quantification; GC-MS, gas chromatography-mass spectrometry; GC-APCI-MS, gas chromatography-atmospheric pressure chemical ionization-mass spectrometry; GC/HRMS, gas chromatography/high-resolution mass spectrometry.

benzene hexachloride, were determined with average concentrations of 151.1, 19.6, and 4.64 mg m⁻³, respectively (Table 6). The reports are higher than the study findings conducted by UNEP in Assella City, which found that PCDFs are the predominant OC in Assella City and ranged from 205.1 to 286.3 ng m⁻³. Ziway is a place where a large number of pesticides are manufactured and stored at the country level.

3.9.5 Food items

POP pesticides and PFOS and its derivatives have been detected in different food items, such as in the residue of rice (Mekonen et al., 2017), cattle meat (Letta and Attah, 2013), fish, fish liver and muscles (Sjöholm, 2015; Ahrens et al., 2016; Melake et al., 2022), khat (Daba et al., 2011), and cow and goat milk (Deti et al., 2014) (Table 7).

TABLE 7 POP chemicals in different food items in Ethiopia.

Food items	Type of POPs	Extraction type	Instrument	Concentration	References
Residue of rice	Endosulfan sulfate	AEH	GC-MS	0.076 ± 0.025*	Siraj et al. (2021)
	p,p'-DDE			0.035 ± 0.013*	
	p,p'-DDT			0.046 ± 0.020*	
	Aldrin			0.06 ± 0.033*	
Meat	o,p'-DDT	SPE	GC-MS	3.24 ± 0.042*	Letta and Attah (2013)
	p,p'-DDT			4.32 ± 0.003*	
	Endosulfan-I			0.06 ± 0.004*	
	Chlorothanolin			0.004 ± 0.001*	
	Aldrin			0.012 ± 0.002*	
	Dieldrin			0.04 ± 0.003*	
	Lindane (̑-HCH)			0.05 ± 0.001*	
Fish muscle	PFAS	SLE	HPLC	Nd-5.8 ng g ⁻¹	Ahrens et al. (2016)
Gelemso <i>Khat</i>	p,p'-DDT	SPE	GC-MS	141.2-973 ug Kg ⁻¹	Daba et al. (2011)
	o,p'-DDT			139.3-399 ug Kg ⁻¹	
Aseno <i>Khat</i>	p,p'-DDT	SPE	GC-MS	194.3-999 ug Kg ⁻¹	
	o,p'-DDT			62.2-224.8 ug Kg ⁻¹	
Cow milk	Aldrin	CRE	GC-MS	Nd-11.6 L ug Kg ⁻¹	Deti et al. (2014)
	a-Endosulfan			Nd-47.8 ug Kg ⁻¹	
	b-Endosulfan			Nd	
	DDT			259-1,230 ug Kg ⁻¹	
Goat milk	Aldrin	CRE	GC-MS	Nd	
	a-Endosulfan			ND-142.1 ug Kg ⁻¹	
	b-Endosulfan			Nd	
	DDT			82.7-874.4 ug Kg ⁻¹	
Fish	PFAS	AUB	LC-MS	Nd-5.78 ng g ⁻¹	Sjöholm (2015)
Fish liver	PFOA	SPE	UPLC-MS/MS	0.1-0.6 ng g ⁻¹	Melake et al. (2022)
	PFDA			0.5-3.2 ng g ⁻¹	
	PFOS			<LOQ-1.2 ng g ⁻¹	
	PFUnDA			0.5-3.9 ng g ⁻¹	

AEH, acetone/ethylacetate/n-hexane; SPE, solid-phase extraction; SLE, solid-liquid extraction; CRE, centrifuge and rotary evaporator; AUB, acetonitrile and ultrasonic bath; GC-MS, gas chromatography-mass spectrometry; HPLC, high-performance liquid chromatography; LC-MS, liquid chromatography-mass spectrometry; UPLC-MS/MS, ultra-high-performance liquid chromatography-tandem mass spectrometry; LOQ, limit of quantification; * is mg kg⁻¹; Nd, not detected.

3.9.6 Human serum

Samples from blood serum can be used as a marker to monitor human exposure to organic pollutants. In a study conducted in Western Ethiopia, small-scale farmers who were exposed and non-exposed to these pollutants were examined. The blood samples of exposed small-scale farmers showed the highest mean concentrations of p,p'-DDT (0.28 ± 0.4 mg L⁻¹), with high levels of p,p'-DDE, p,p'-DDT, and heptachlor also identified (Afata et al., 2021).

3.10 Weaknesses of regulatory and non-regulatory measures for chemical management in Ethiopia

Except for the proclamation aiming at controlling and regulating pesticides, no legislation specifically addresses other POP chemicals in Ethiopia (Ministry of Agriculture, 2010). As this could be considered a clear gap, it is important to have specific legislation on the management of other POP chemicals. In addition, there is

TABLE 8 POP chemicals detected in human blood.

Location	Type of POPs	Extraction type	Instrument	Concentration	References
Jimma	DDT	EEH	GC-ECD	5.20 ± 4.8 ^a µg L ⁻¹	Mekonen et al. (2021)
				4.37 ± 2.8 ^b µg L ⁻¹	
	Heptachlor	EEH	GC-ECD	6.90 ± 4.3 µg L ⁻¹	
				9.15 ± 3.8 µg L ⁻¹	
	Aldrin	EEH	GC-ECD	1.20 ± 1.1 µg L ⁻¹	
				1.45 ± 1.4 µg L ⁻¹	
	Endrin	EEH	GC-ECD	3.44 ± 0.9 µg L ⁻¹	
				1.75 ± 2.2 µg L ⁻¹	
	Endosulfan	EEH	GC-ECD	1.33 ± 0.65 µg L ⁻¹	
				3.72 ± 2.04 µg L ⁻¹	
Western Ethiopia	p p'-DDT	SEM	GC-ECD	0.28 ± 0.4 ^c mg L ⁻¹	Afata et al. (2021)
				0.25 ± 0.45 ^d mg L ⁻¹	

EEH, ethyl ether/hexane; SEM, Soxhlet extraction method; GC-ECD, gas chromatography electron capture detector.

^aCase.

^bControl.

^cExposed farmer.

^dNon-exposed farmer.

weak coordination among and within responsible institutions. This is a concern in Ethiopia when it comes to the implementation of regulatory measures in chemical management (Akele and Tarekegn, 2017). For instance, there is no active collaboration among the Ministry of Agriculture, the Customs and Revenue Authority, and the EPA. The existing institutional framework does not have a way for coordination because there is no strong line of communication and information sharing among the responsible regulatory bodies. There is a challenge in handling contraband and adulteration, and the shortage of inspectors and vehicles for monitoring purposes bedevils the adequate control of POP chemicals (Debela et al., 2020b). There is also no structure and practice of information exchange on the movement or management of POP chemicals with the customs authority, different ministers, and industries.

Data on chemicals and their safety are available from a variety of governmental and non-governmental organizations, including the ministries of agriculture, trade and industry, customs, and mines and energy. The available information on chemicals in Ethiopia is not systematically organized and easily accessible despite the fact that some institutions have country-wide data on certain chemicals. There is a lack of information on industries suspected of using POP chemicals, their production levels, and the estimated or modeled amount of such chemicals released into the environment.

The current laws related to the management and control of POPs in Ethiopia are unclear, especially in terms of the roles and responsibilities of the relevant organizations. Various government offices have their own regulations concerning the chemicals originating from their respective sectors. Moreover, there are no laws regulating the manufacturing, importing, handling, transport, storage, or disposal of hazardous chemicals, whether industrial or

otherwise. Currently, legal frameworks to address these issues are either under development or pending adoption.

3.11 Gaps in institutional capacity

The overall technical infrastructure concerning chemical management within the country is very weak. Industries dealing with chemicals do not have the required experts for the handling of chemicals, and professionals are not well versed with the knowledge and skills that are required for dealing with chemicals. In addition, chemicals are not properly labeled (Ejigu and Mekonnen, 2005; Mequanint et al., 2019; Debela et al., 2020b).

4 Conclusion

This study provides an overview of the status of POPs in Ethiopia by gathering data from various governmental and private institutions involved in the use or regulation of POPs in the country. The findings indicate a significant accumulation of Annex A, B, and C POPs, such as PCBs from electric transformers and POP pesticides in Ethiopia. Notably, the review of the existing literature demonstrates that various environmental matrices, including soil, waterbodies, sediments, food items, and air, as well as human blood, have substantial levels of different POPs. This study has identified several regulatory and non-regulatory gaps in chemical management in the country. Specifically, there is insufficient information available on various POP pollutants, except for endosulfan, at the national level, and no legislation directly addresses other POP chemicals except the pesticide

proclamation. Therefore, it is crucial to have specific legislation targeted toward the management of POP chemicals in Ethiopia, achieved by enhancing collaboration and coordination among different regulatory bodies, harmonizing fragmented laws on POP management and control, and building institutional capacity.

Author contributions

SAD, IS, and MG were involved in conceptualization and data curation; SAD, IS, CD, YT, DB, and MG wrote the original draft, reviewed and edited the manuscript. All authors contributed to the article and approved the submitted version.

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Supplementary material

The supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fenvs.2023.1182048/full#supplementary-material>

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Glossary

DDT	Dichlorodiphenyltrichloroethane
EPA	Environmental Protection Agency
EMEFCC	Ethiopian Ministry of Environment, Forest, and Climate Change
FAO	Food and Agriculture Organization
LC-PFCAs	Long-chain perfluorocarboxylic acids, their salts, and related compounds
NIP	National Implementation Plan
HCB	Hexachlorobenzene
HCH	Hexachlorocyclohexane
o,p'-DDT	1-Chloro-2-[2,2,2-trichloro-1-(4-chlorophenyl)ethyl]-benzene
OCPs	Organochlorine pesticides
p,p'-DDE	p,p'-Dichlorodiphenyldichloroethylene
p,p'-DDT	p,p'-Dichlorodiphenyltrichloroethane
USAID	United States Agency for International Development
PBDEs	Polybrominated diphenyl ethers
PCBs	Polychlorinated biphenyls
PCDD/Fs	Polychlorinated dibenzo-p-dioxins/dibenzofurans
PFASs	Polyfluoroalkyl substances
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFOSF	Perfluorooctanesulfonyl fluoride
PFUnDA	Perfluoroundecanoic acid
PFDA	Perfluorodecanoic acid
POPs	Persistent organic pollutants
α-HCH	alpha-Hexachlorocyclohexane
β-HCH	beta-Hexachlorocyclohexane
γ-HCH	gamma-Hexachlorocyclohexane (lindane)