



India-Norway Cooperation Project on Capacity Building for Reducing Plastic and Chemical Pollution in India (INOPOL)



2026

MANAGING PERSISTENT ORGANIC POLLUTANTS IN TAMIL NADU, INDIA

FROM SCIENCE TO STRATEGY AND ACTION FRAMEWORK



INOPOL (2026) Managing Persistent Organic Pollutants in Tamil Nadu, India: From Science to Strategy and Action Framework

Acknowledgements

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Authors

NIVA: Sissel Brit Rannekleiv, Emmy Nøklebye, Amy-Kristine Andersen, Merete Grung, Hans Nicolai Adam

Mu Gamma Consultants: Avanti Roy Basu, Kriti Akansha, Girija K Bharat, Nathaniel Bhakupar Dkhar

SRMIST: Paromita Chakraborty, Sarath Chandra, Mithun Karayi, Pavithra K, Yuvanesh J, Irshana Shajahan

Toxics Link: Piyush Mohapatra, Alka Dubey, Deepak Marathe, Vidhi Mathur

Disclaimer

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Designed by

Paper Play, Delhi. E: contact@paperplay.co.in

Foreword

ANDREAS B. SCHEI

**COUNSELLOR FOR CLIMATE & ENVIRONMENT,
ROYAL NORWEGIAN EMBASSY IN NEW DELHI**

It is a pleasure to present this report titled '*Managing Persistent Organic Pollutants in Tamil Nadu, India: From Science to Strategy and Action Framework*', developed under the India–Norway Cooperation Project on Capacity Building for Reducing Plastic and Chemical Pollution in India (INOPOL). The INOPOL is part of the India Norway Marine Pollution Initiative, which is a bilateral arrangement to address marine and plastic pollution in India.

Chemical pollution is a shared global challenge that calls for strong international collaboration and action. There are few institutions that have the background and the expertise to understand and act upon chemical pollution. INOPOL has brought together some of the best Indian and Norwegian institutions that work on Persistent Organic Pollutants (POPs). INOPOL partners have worked closely with the state government of Tamil Nadu to monitor, analyse and suggest management measures for POPs.

The action plan developed in this report contributes to India's efforts under the Stockholm Convention and to our broader bilateral engagement on environmental protection. I commend all partners involved in bringing out this important report.

Andreas B. Schei

Counsellor for Climate & Environment, Royal Norwegian Embassy in New Delhi

Foreword

THORJØRN LARSEN

**DEPUTY CHIEF EXECUTIVE OFFICER,
NORWEGIAN INSTITUTE FOR WATER RESEARCH**

Persistent Organic Pollutants (POPs) pose long-term risks to ecosystems and human health and addressing them requires strong scientific foundations and sustained institutional capacity. It is therefore with great pride that we present this '*Managing Persistent Organic Pollutants in Tamil Nadu, India: From Science to Strategy and Action Framework*', developed under the INOPOL project.

At NIVA, we see science-based environmental management as central to effective policy and practice. This Action Plan reflects the evolution of INOPOL from generating baseline knowledge to supporting more targeted and solution-oriented approaches, combining new monitoring data with policy analysis to strengthen POPs governance in Tamil Nadu.

This work would not have been possible without the close collaboration of our Indian partners – Mu Gamma Consultants, SRM Institute of Science and Technology, Toxics Link, and CIPET – and the strong support of the Royal Norwegian Embassy in New Delhi. On behalf of NIVA, I extend my sincere thanks to the Embassy and the Ministry of Foreign Affairs for their trust and commitment to long-term capacity building. I hope this Action Plan will serve as a valuable resource for authorities, researchers, and practitioners working to reduce chemical risks and protect public health.

Thorjørn Larsen

Deputy Chief Executive Officer, Norwegian Institute for Water Research

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List of ABBREVIATIONS AND ACRONYMS

α -HBCD	alpha-Hexabromocyclododecane	EU	European Union
BAT	Best Available Techniques	γ -HCH	gamma-Hexachlorocyclohexane
BDEs	Brominated Diphenyl Ethers	GEF	Global Environment Facility
BEP	Best Environmental Practices	HBCD	Hexabromocyclododecane
BFRs	Brominated Flame Retardants	HCH	Hexachlorocyclohexane
BIS	Bureau of Indian Standards	IEC	Information, Education, and Communication
BPA	Bisphenol A	IIT	Indian Institute of Technology
CIPET	Central Institute of Petrochemicals Engineering and Technology	INOPOL	India-Norway cooperation project on capacity building for reducing plastic and chemical pollution in India
CPCB	Central Pollution Control Board		
CPRI	Central Power Research Institute	INGOs	International non-governmental organizations
CSIR	Council of Scientific and Industrial Research	IPEN	International Pollutants Elimination Network
CSIR-NEERI	Council of Scientific and Industrial Research - National Environmental Engineering Research Institute	IPM	Integrated Pest Management
		IPM-CRSP	Integrated Pest Management-Collaborative Research Support Program
CSIR-NIIST	National Institute for Interdisciplinary Science and Technology	IQR	Interquartile Range
CSR	Corporate Social Responsibility	ITI	Industrial Training Institute
DDE	Dichlorodiphenyldichloroethylene	LC-PFCA	Long-chain perfluoroalkylcarboxylic acids
DDT	Dichlorodiphenyltrichloroethane	LC-PFSA	Long-chain perfluoroalkylsulfonic acids
DecaBDE	Decabromodiphenyl ether	LRTAP	Long-Range Transboundary Air Pollution
DIIPC	Department of Industries, Investment Promotions and Commerce	MCL	Maximum Contaminant Level
ECCF	Environment, Climate Change and Forests Department	MFA	Norwegian Ministry of Foreign Affairs
EMIS	Environmental Monitoring and Information System	MGC	Mu Gamma Consultants Private Limited
ENDO	Endosulfan	MoA&FW	Ministry of Agriculture and Farmers Welfare
EQS	Environmental Quality Standard		

MoC&F	Ministry of Chemicals and Fertilizers	REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
MoEF&CC	Ministry of Environment, Forest and Climate Change	SAICM	Strategic Approach to International Chemicals Management
MoH&FW	Ministry of Health and Family Welfare	SC-PFCA	Short-chain perfluoroalkylcarboxylic acids
MoP	Ministry of Power	SC-PFSA	Short-chain perfluoroalkylsulfonic acids
MS	Midstream	SCCPs	Short-chain chlorinated paraffins
NABL	National Accreditation Board for Testing and Calibration Laboratories	SDGs	Sustainable Development Goals
NGC	National Green Corps	SIDCO	Small Industries Development Corporation
NGOs	Non-governmental organizations	SIPCOT	State Industries Promotion Corporation of Tamil Nadu
NIP	National Implementation Plan	SOPs	Standard Operating Procedures
NIVA	Norwegian Institute for Water Research	SPCBs	State Pollution Control Boards
NR	Noyyal River	SRMIST	SRM Institute of Science and Technology
OCPs	Organochlorine pesticides	TIDCO	Tamil Nadu Industrial Development Corporation
PBDEs	Polybrominated Diphenyl Ether	TNAU	Tamil Nadu Agricultural University
PCBs	Polychlorinated Biphenyls	TNFI	Tamil Nadu Fishnet Initiative
PCDD	Polychlorinated Dibenzop-dioxins and Dibenzofurans	TNPCB	Tamil Nadu Pollution Control Board
PeCB	Pentachlorobenzene	UNECE	United Nations Economic Commission for Europe
PFAS	Per- and polyfluoroalkyl substances	UNEP	United Nations Environment Programme
PFCA	Perfluoroalkylcarboxylic acids	USEPA	United States Environmental Protection Agency
PFHxS	Perfluorohexanesulfonic acid	UV	Ultraviolet
PFOA	Perfluorooctanoic acid	ZLD	Zero Liquid Discharge
PFOS	Perfluorooctanesulfonic acid		
PIC	Prior Informed Consent		
POPs	Persistent Organic Pollutants		
PPP	Public-Private Partnership		
ppt	Parts Per Trillion		

| Preface

This POPs action plan has been developed under the India–Norway Cooperation Project on Capacity Building for Reducing Plastic and Chemical Pollution in India (INOPOL). INOPOL provides a collaborative framework for strengthening scientific knowledge, monitoring capacity and policy implementation related to plastic pollution and persistent organic pollutants (POPs) in India. The project is led by the Norwegian Institute for Water Research (NIVA) in close collaboration with Mu Gamma Consultants Pvt. Ltd. (MGC) and in partnership with Indian institutions, including the Central Institute of Petrochemicals Engineering and Technology (CIPET), Toxics Link, and SRM Institute of Science and Technology (SRMIST).

The first phase of INOPOL (2019–2022) focused on industrial regions in Gujarat, where the project generated science-based evidence on land-based sources, riverine transport and environmental releases of plastics and POPs. Building on this foundation, the second phase (2022–2025) adopts a more targeted and solution-oriented approach in Tamil Nadu, supporting the Government of Tamil Nadu in assessing sources of POPs, strengthening monitoring systems, and identifying opportunities to reduce releases to terrestrial, freshwater and marine ecosystems in line with India’s commitments under the Stockholm Convention.

The purpose of this POPs action plan for Tamil Nadu is to provide a science-informed framework for identifying contamination hotspots, strengthening management practices, and reducing the risks associated with legacy and emerging POPs. The plan aims to support safe and sustainable management of POPs in alignment with national priorities and India’s commitments under the Stockholm Convention, while strengthening linkages between the management and governance of chemicals, pollution, and public health protection.

Specifically, the action plan seeks to strengthen regulatory implementation, raise awareness among relevant stakeholders, assess gaps in environmental monitoring systems, support research on the sources, fate and impacts of POPs, and identify practical challenges and opportunities for adopting the best available techniques (BAT) and best environmental practices (BEP) across key sectors. It further emphasises the role of capacity building, inter-departmental coordination, and diversified financing mechanisms in enabling effective and sustained POPs management. While focused on Tamil Nadu, the approaches outlined in this action plan are designed to be adaptable to other Indian states, contributing to broader national efforts to reduce POPs-related environmental and public health risks through evidence-based and coordinated governance.



Executive SUMMARY

Persistent Organic Pollutants (POPs) pose a significant long-term risk to human health and the environment due to their persistence, bioaccumulation, toxicity and capacity for long-range transport. In India, decades of pesticide use, rapid industrialisation and expanding waste streams have contributed to widespread environmental contamination and human exposure. Gaps in monitoring, limited treatment infrastructure and uneven regulatory enforcement compound these challenges.

This POPs Action Plan for Tamil Nadu has been developed under the India–Norway Cooperation Project on Capacity Building for Reducing Plastic and Chemical Pollution in India (INOPOL). It builds on new scientific evidence generated during INOPOL Phase II, including environmental monitoring of legacy and emerging POPs in air, water, sediments and biota, with a particular focus on the Cauvery River basin and identified industrial and open-burning hotspots.

The findings confirm that POPs contamination in Tamil Nadu is closely linked to industrial clusters, informal waste-management practices and open burning of plastics. In several locations, measured concentrations exceed international environmental quality standards, indicating potential risks to ecosystems and human health.

At the same time, the analysis highlights important opportunities for strengthening POPs governance in the state. Tamil Nadu benefits from a strong network of universities, research institutions and technical laboratories, as well as active environmental education programmes and emerging initiatives within the Tamil Nadu Pollution Control Board (TNPCB) that can be leveraged to build a more robust knowledge base

and monitoring system for POPs. These institutional strengths provide a solid foundation for advancing more preventive and coordinated approaches to chemical risk management.

This action plan sets out a phased and practice-oriented framework to strengthen the management of both legacy and emerging POPs in Tamil Nadu. The strategy focuses on strengthening institutional coordination, inventories and monitoring systems; enhancing regulatory implementation and enforcement in line with India's National Implementation Plan under the Stockholm Convention; and promoting safer alternatives to POP-containing chemicals and products through life-cycle approaches. It also places strong emphasis on building technical capacity across regulators, industries and laboratories, and on supporting stakeholder engagement, awareness and behaviour-change initiatives to reduce exposure risks, particularly among vulnerable groups.

The action plan recognises that effective POPs management requires sustained investment in skills, infrastructure and governance, alongside coordinated action between regulatory authorities, industry, research institutions and civil society. By translating scientific evidence into a structured and implementable roadmap, it provides a strategic and operational tool to reduce chemical risks, protect public health and strengthen environmental governance in Tamil Nadu. Through a combination of science-based decision-making, institutional collaboration and inclusive engagement, the action plan aims to support the state in advancing safer, more resilient and more equitable approaches to chemicals management in the years ahead.



Chapter 1

INTRODUCTION

POPs are a group of toxic chemicals characterised by their persistence, bioaccumulation, long-range transport, and adverse effects on human health and aquatic animals (Akhtar et al., 2021; Najam and Alam, 2023). These chemicals undergo extremely slow environmental degradation through chemical, biological, or photolytic processes, and at times, they fail to meaningfully degrade, which results in their persistence in soils, sediments, water bodies, and biota for very long periods of time (Akhtar et al., 2021). POPs may be produced intentionally or generated as unintentional by-products of industrial activities. Their capacity for long-range transport through air and water enables them to travel far from their points of release, leading to contamination even in remote regions such as the Arctic and Antarctica (Miglioranza et al., 2022; Kallenborn et al., 2015).

A defining characteristic of POPs is their intrinsic chemical toxicity, which enables them to interfere with key biological and biochemical processes even at low concentrations. Exposure to POPs has been widely associated with cytotoxic, endocrine-disrupting, immunotoxic, and carcinogenic effects. These toxic actions can result in a range of adverse health outcomes, including severe effects on the liver, hormonal regulation, reproductive function, and immune system (Raheem et al., 2025). In addition, POPs are highly lipophilic and hydrophobic, properties that promote their persistence in soils, sediments, and the fatty tissues of animals and humans (Karnwal et al., 2024; Aladl et al., 2025; Kiki et al., 2025). These physicochemical characteristics facilitate their bioaccumulation in aquatic organisms and subsequent biomagnification along food chains. These characteristics make POPs

a long-standing and complex environmental and public health challenge that requires sustained and coordinated responses.

Recognising these risks, the Stockholm Convention on Persistent Organic Pollutants established a global framework for the elimination, restriction, and reduction of POPs production, use, and release (Stockholm Convention, 2004). India, as a signatory to the Stockholm Convention, has committed to implementing National Implementation Plans (NIPs) to address POPs in the environment (NIP, Government of India, 2011). In line with these commitments, the Ministry of Environment, Forest and Climate Change (MoEF&CC) notified the Regulation of POPs Rules, 2018, which prohibited the manufacture, trade, use, import, and export of seven hazardous chemicals listed under the Stockholm Convention. In 2020, the Union Cabinet approved the ratification of seven new POPs. Despite these regulatory advances, India continues to face significant challenges in managing POPs, including widespread pesticide use in agriculture, limited facilities to control industrial emissions, gaps in monitoring infrastructure, and uneven enforcement of existing regulations.

Tamil Nadu illustrates both the scale and the complexity of these challenges. As a major industrial and agricultural state in southern India, Tamil Nadu hosts diverse sectors such as automobiles, textiles, leather, chemicals, electronics, and agricultural processing. Many of these sectors are associated with the intentional use of POPs or with unintentional releases through industrial processes, waste handling, and emissions. Empirical studies have documented the occurrence of POPs in soils,

surface waters, sediments, and biota across the state, with implications for human health and aquatic ecosystems (Kumarasamy et al., 2012; Selvaraj et al., 2015; Murugan and Vasudevan, 2017; Rex and Chakraborty, 2022; Vimalkumar et al., 2018; INOPOL, 2025). These patterns are further shaped by rapid urbanisation, expanding waste streams, and informal recycling and disposal practices, which create additional exposure pathways in and around industrial clusters and river corridors.

These dynamics highlight the need for a comprehensive, evidence-based and implementation-oriented approach to POPs management in Tamil Nadu, one that moves beyond fragmented interventions towards coordinated governance, strengthened monitoring, and preventive action across the full lifecycle of chemicals and materials. Effectively addressing POPs therefore requires not only regulatory controls but also improved institutional coordination, enhanced technical capacity, and sustained engagement with industries, communities, and other stakeholders.

It is in this context that the present POPs action plan has been developed. Building on scientific evidence and stakeholder consultations conducted under the INOPOL project, the action plan proposes a phased and practice-oriented framework to support the effective management of both legacy and emerging POPs in Tamil Nadu. Particular attention is given to linkages between POPs, plastic production, waste management, and informal recycling practices, recognising them as critical nodes of environmental release and human exposure.

A central objective of the action plan is to strengthen institutional capacity for POPs governance by improving monitoring systems,

regulatory implementation, and coordination across departments. It leverages existing institutional and societal strengths through stakeholder engagement, capacity building, research and innovation, public awareness initiatives, and the promotion of safer chemical and material alternatives. By doing so, the action plan positions POPs management as both a regulatory responsibility and a cross-cutting development challenge that requires sustained collaboration among environmental authorities, industry, civil society, and research institutions.

The action plan also provides an integrated overview of existing practices, regulations, and international commitments, including India's obligations under the Stockholm Convention, and identifies opportunities to enhance enforcement and compliance at the state level. By addressing technological, institutional, and social constraints, it outlines a focused strategy for Tamil Nadu that prioritises hotspot monitoring, stakeholder collaboration, and practical, science-driven solutions to reduce emissions and prevent future contamination.

Designed as a policy input document, this action plan offers decision-makers structured guidance to identify POPs production, use, and contamination across the lifecycle of materials and to assess associated risks to human health and the environment. It responds directly to institutional, regulatory, and governance challenges while emphasising the importance of building on existing capabilities and partnerships. Together, these elements position the action plan as both a strategic and operational tool for advancing more effective, preventive, and equitable POPs management in Tamil Nadu.





Chapter 2

SITUATION ANALYSIS

POPs have shaped India's environmental and regulatory landscape for more than half a century, evolving from intensive organochlorine pesticide use to complex inputs from rapid industrialisation, urbanisation, and expanding consumer product markets. This chapter examines how this transition has created overlapping layers of legacy contamination and emerging chemical threats, with particular attention to PFAS as "forever chemicals" and to the adequacy of current management responses in India. By tracing the historical use of POPs, identifying contemporary source categories, assessing ecological and human health risks, and reviewing the policy architecture from global conventions to national and state-level implementation, the chapter provides a situation analysis that links scientific evidence with governance challenges. It also highlights India's growing engagement with safer alternatives and best available techniques, underscoring the need for integrated risk assessment and cross-sectoral coordination as the country updates its National Implementation Plan under the Stockholm Convention.

2.1 History of POPs in Indian environments

POPs have been part of India's environmental landscape for several decades, primarily due to the country's extensive use of organochlorine pesticides and rapid industrialisation. Early applications of POPs such as DDT, aldrin, and endrin for agricultural pest control and vector-borne disease management were widespread during the 1950s–1980s (Li et al., 2023). Over time, industrial growth led to unintentional

releases of POPs through combustion, metallurgical processes, and waste incineration (Chakraborty et al., 2022). Although several of these compounds have been banned or restricted (such as DDT) under Indian legislation and the Stockholm Convention, residues continue to be detected in soil, sediments, and biota, highlighting their persistence and long-range environmental mobility (INOPOL, 2021a).

Environmental and human exposure

Studies conducted across India have reported detectable concentrations of legacy POPs in multiple environmental matrices, including surface waters, sediments, and fish, with obsolete pesticides such as dieldrin and elevated levels of endosulfan and DDT identified in major river systems such as the Tapi River (INOPOL, 2022). The Central Pollution Control Board (CPCB) has also identified critically polluted areas such as Ankleshwar, Ahmedabad, and Vapi, where emissions of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) arise mainly from waste incineration and metal processing (CPCB, 2022).

Similar findings have been reported from southern India, where investigations in Tamil Nadu revealed the presence of organochlorine pesticide residues, including HCH, DDT, and endosulfan in water, sediments, and aquatic species from riverine and coastal systems such as the Cauvery and Thamirabharani Rivers and the Bay of Bengal (Arisekar et al., 2019; Patil et al., 2015). Human exposure has also been documented through biomonitoring studies. Concentrations of POPs, like polychlorinated biphenyls (PCBs), dioxins, and organochlorine pesticides, were detected in

human breast milk samples from urban centres, including Chennai and Kolkata, indicating maternal transfer and dietary exposure pathways (Rex and Chakraborty, 2024; Someya et al., 2010). Studies have also identified elevated POP levels in fish, seaweed, and bird eggs, demonstrating bioaccumulation across trophic levels (Fremlin et al., 2020).

New POPs and data gaps

In recent years, attention has expanded to include newly listed POPs such as brominated flame retardants (DecaBDE, Hexabromobiphenyl, HBCD), per- and polyfluoroalkyl substances (PFAS), short-chain chlorinated paraffins (SCCPs), and UV stabilisers (UV-328) (Ram Charitra Sah & Keshab Raj Joshi, 2011). These compounds are widely used in industrial manufacturing, textiles, automotive products, and electronic components. Evidence from various Indian studies indicates their occurrence in wastewater, sludge, and atmospheric samples near industrial hubs and informal e-waste recycling zones. Air and soil samples from Chennai's informal e-waste clusters revealed elevated levels of PBDEs and PCBs, suggesting continuing emissions from legacy and secondary sources (Chakraborty et al., 2021; Chakraborty et al., 2016).

Despite ongoing research, comprehensive data on new POPs remain limited. India's updated National Implementation Plan (NIP) acknowledges the need for improved inventories, analytical methods, and monitoring infrastructure. Information gaps persist on stockpiles, unintentional releases, and human health impacts, particularly for newly listed industrial chemicals. Addressing these gaps through systematic monitoring, the development of cost-effective detection techniques, and coordinated clean-up programmes will be critical for mitigating exposure risks.

Overall, the history of POPs in India is a transition from agricultural to industrial sources of contamination, with continued challenges in

managing legacy pollutants and emerging chemicals of concern. Strengthened monitoring, regulation, and inter-agency coordination are essential to safeguard environmental and public health from long-term POP exposure.

2.2 Source categories and common uses

Waste management and recycling practices

E-waste recycling and plastic waste management are rapidly emerging as critical POPs sources. Informal recycling of electronic components often involves open burning or acid leaching, leading to emissions of PCBs, dioxins, furans, and brominated flame retardants (Chakraborty et al., 2025). Similarly, the plastic manufacturing and recycling sectors utilise flame retardants, surfactants, and UV stabilizers such as Dechlorane Plus, PFAS, and UV-328, which can leach during disposal or incineration (INOPOL, 2021b). Open burning of municipal and industrial waste further contributes to unintentional POP formation (Chakraborty et al., 2022).

Pesticides and agricultural inputs

India has a long history of organochlorine pesticide (OCP) use, with compounds such as DDT, aldrin, endrin, and hexachlorocyclohexane (HCH) leaving persistent residues in soils, sediments, and food chains (TERI, 2018). Although several of these chemicals are banned under national regulations and the Stockholm Convention, traces continue to be detected in environmental matrices and biological samples, indicating both historical contamination and possible illegal or unintentional usage (Chakraborty et al., 2015). Continued reliance on pesticide formulations containing hazardous active ingredients has hastened the need for strict regulatory oversight and promotion of safer alternatives.

Chemical and manufacturing industries

India's rapidly expanding chemical and petrochemical industries are among the primary sources of POPs. Basic and speciality chemicals, including chlorinated solvents, plasticizers, and intermediates, contribute to the production and unintentional formation of POPs during manufacturing, processing, and waste disposal (ToxicsLink, 2018). Industrial clusters engaged in petrochemical processing, fertilizer manufacturing, and paint and coating production are known to generate POPs such as hexachlorobenzene and PCBs as by-products (Li et al., 2023). Chlorinated paraffins, widely used as plasticizers and lubricants in metalworking fluids, coatings, and sealants, also pose concerns for persistence and bioaccumulation.

Automobile and electronics sectors

The automobile industry employs a range of POPs-related substances in wiring, insulation, seat foams, coatings, and lubricants. Halogenated flame retardants, including PBDEs, are integral to components requiring high heat tolerance for both internal combustion engine and electric vehicles (Melo et al., 2025). PFAS-based coatings improve resistance to heat, water, and oil in both interior and exterior automotive parts (Glüge et al., 2020). Similarly, in the electronics sector, brominated flame retardants, PFAS, and PCBs have historically been used in printed circuit boards, cables, connectors, capacitors, and insulators (Morf et al., 2005). While PCBs are now banned, residues persist in obsolete equipment and wastes, and improper disposal practices can result in ongoing emissions.

Textile and leather industries

The textile and leather sectors are major users of halogenated flame retardants and chlorinated paraffins to enhance product durability and flame resistance. POPs like PFAS are commonly applied

in fabrics, carpets, and protective clothing to impart water- and stain-repellent properties (Figuère et al., 2025). Though beneficial in enhancing performance, their persistence and mobility result in environmental contamination through industrial wastewater discharges, sludge, and solid waste. The use of UV stabilizers such as UV-328 in textiles, coatings, and outdoor fabrics is also of concern, given their recent inclusion in the Stockholm Convention as POPs (Wania and McLachlan, 2024).

Effluent treatment and industrial discharges

Effluent treatment in industrial areas plays a vital role in reducing POP loadings; however, inconsistent compliance and poor operational efficiency often lead to incomplete removal (Singh et al., 2023). POPs such as dioxins, furans, and other halogenated persistent compounds can be carried in sludge and leach into receiving waters (Thathola et al., 2025). Monitoring gaps, limited laboratory infrastructure, and inadequate waste segregation further exacerbate these challenges.

Across sectors, POPs continue to enter the environment through both legacy contamination and contemporary industrial applications.

2.3 Risk assessment

The risk assessment of POPs involves estimating exposure through environmental media and food chains and comparing these levels with toxicological benchmarks to characterise potential risks to ecosystems and human health. These chemicals pose a multifaceted threat as they remain stable in the environment for years, accumulate in food chains, and cause chronic health effects even at low concentrations. The assessment process typically encompasses hazard identification, exposure assessment, dose-response analysis, and risk characterisation, forming the basis for regulatory decisions and priority interventions under the Stockholm Convention.

Environmental and human exposure pathways

In India, multiple studies have documented POP residues across environmental matrices, including air, soil, sediments, water, and biota, as well as in human biological samples. Key exposure routes include dietary intake (through contaminated fish, milk, and crops), contaminated drinking water (PFAS), inhalation near industrial zones or waste-burning sites, and dermal contact through occupational exposure. Legacy POPs such as DDT, endosulfan, and HCH are still detected in agricultural soils and aquatic ecosystems, particularly in riverine catchments receiving agricultural runoff. Studies from southern India have reported organochlorine pesticides in fish and bird tissues, while research from northern and western India has shown PCBs and dioxins in industrial areas and e-waste zones (Toxics Link, 2018). The continued detection of these compounds highlights both past and ongoing emissions from unregulated sources.

Human health hazards

The toxicological effects of POPs include endocrine disruption, reproductive toxicity, immunosuppression, and carcinogenicity. Long-term dietary exposure to OCPs and PCBs has been associated with developmental effects in children and metabolic disorders in adults (Windsor et al., 2019). Biomonitoring studies in Indian urban areas have found detectable levels of DDT, PCBs, and dioxins in human breast milk and blood, confirming maternal and neonatal exposure (Devanathan et al., 2009; Gill et al., 2020; Someya et al., 2010). Occupational exposure remains a concern among workers in pesticide manufacturing, transformer repair, and informal recycling sectors, where inadequate safety practices and poor waste handling can significantly increase risk.

Ecological threats

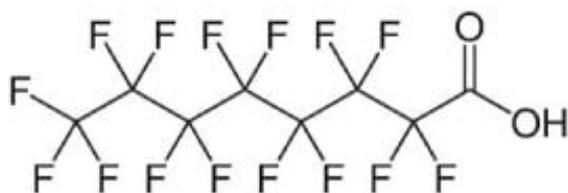
POPs pose severe ecological threats by bioaccumulating in aquatic food webs, leading to reproductive and behavioural effects in fish, birds,

and mammals. In Indian coastal and freshwater systems, the presence of DDTs, HCHs, and PCBs in sediments and aquatic organisms indicates potential sublethal impacts on biodiversity. Studies on avian species have shown eggshell thinning and reduced hatching success correlated with elevated POP concentrations (Campioni et al., 2024; Kamata et al., 2020). The persistence of dioxins and furans from open waste burning and industrial combustion further aggravates ecological risk through atmospheric deposition and soil contamination.

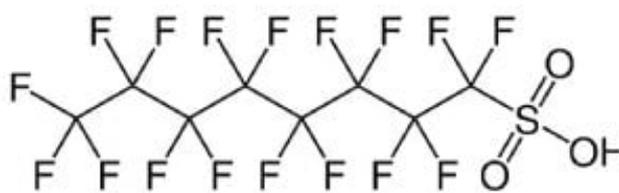
While India has developed inventories and regulatory controls for several POPs, systematic risk assessment frameworks remain limited. Lack of baseline data for new POPs and limited analytical infrastructure has fragmented monitoring across states. Current risk evaluations are often chemical-specific and do not adequately account for combined or synergistic effects. Strengthening institutional capacity for exposure modelling, toxicological testing, and ecological risk evaluation is essential.

2.4 Forever chemicals: PFAS contaminants of emerging concern

PFAS are a large class of more than several thousand (Wang et al., 2021) synthetic chemicals globally used since the 1930s in a wide range of products. Due to their chemical properties, such as extreme durability and resistance to breakdown, they are often referred to as “forever chemicals”. Their unique chemical properties make them highly useful but also environmentally problematic. PFAS and POPs share several similarities; for example, they are highly persistent, both can bioaccumulate in the environment, they are susceptible to long-range air transportation, and they may cause severe human health effects and negative effects on organisms in the environment (Glüge et al., 2020; Gaines, 2023). Figure 2.1 shows the most known PFAS: PFOS (perfluorooctanesulfonic acid) and PFOA (perfluorooctanoic acid).



Perfluorooctanoic acid (PFOA)



Perfluorooctanesulfonic acid (PFOS)

Figure 2.1: Chemical structure of PFOA ($C_8F_{15}COOH$) and PFOS ($C_8F_{17}SO_3H$).

PFAS versus traditional legacy POPs

PFAS are also classified as POPs under international and regional frameworks, but there are also many differences between PFAS and traditional legacy POPs, for example:

- PFAS are considered more persistent than traditional POPs due to the carbon-fluorine (C-F) bond is considerably stronger and more difficult to break than the carbon-bromine (C-Br) and carbon-chlorine (C-Cl) bonds.
- PFAS are generally more water soluble than traditional POPs due to the dissociation of their carboxylic or sulfonic acid functional groups; however, their solubility and mobility are strongly dependent on chain length, with short-chain PFAS exhibiting high aqueous mobility, while long-chain compounds ($\geq C8$) are less water soluble and more prone to sorption, though they can still be transported to groundwater.
- Due to the hydrophobic tail (C-F) and the hydrophilic head (COO- or SOOO-), PFAS act as surfactants and may accumulate at the air-water interphase, while POPs tend to bind to organic carbon in the aquatic environment and accumulate in sediments.
- The properties of PFAS, with a hydrophobic tail and hydrophilic head (surfactants), make it difficult to remove the contaminants from drinking water and sewage systems using conventional treatment methods.
- PFAS accumulate in proteins (and therefore in blood), while POPs accumulate in fatty tissues.
- PFAS are more mobile (especially those defined as short chain) in the environment compared to POPs, due

to the anionic charge of the molecule at pH below 7.

- PFAS are widely used in consumer goods and industrial products, while POPs were mainly used for pest control and in industrial manufacturing and produced as by-products from combustion and industrial processes.
- PFAS is a considerably larger group of chemicals compared to traditional POPs.
- Globally, PFAS are increasingly regulated, like the Stockholm Convention, while most POPs are already banned.

(Sources: Domingo & Nadal, 2019; Nzeribe et al., 2019; Kwiatkowski et al., 2020; Abunada et al., 2020; De Silva et al., 2020; Panieri et al., 2022; Amen et al., 2023; Brunn et al., 2023)

Routes of exposure for humans

Today PFAS are ubiquitously found in the environment due to widely long use and lack of regulations. It is well known that food and drinking water are major routes of exposure for humans. But other sources of exposure are important, like food packaging material, consumer products, indoor dust, and workers using or handling PFAS-containing products (Ackerman Grunfeld et al., 2024; Ohoro & Ngole-Jeme, 2026).

In a recent global study, PFAS concentration data for over 45,000 surface and groundwater samples were assessed (Ackerman Grunfeld et al., 2024). Results showed that a substantial fraction of sampled waters exceeded PFAS drinking water guidance values, with the extent of exceedance

depending on the jurisdiction and PFAS source. USEPA's proposed limits (4 ppt) for PFOA/PFOS are among the most stringent globally. Canada's total PFAS approach (< 30 ng/L) is for a wide range of substances. The EU standards use both the sum of selected PFAS and total PFAS thresholds. These varying guidance values influence how many water sources are classified as exceeding "safe levels" in the global assessment (of Ackerman Grunfeld et al., 2024). The findings also showed that current monitoring practices probably underestimate the amount of PFAS in the environment, as only a limited number of PFAS are typically quantified and of regulatory concern. Monitoring data from drinking water, both surface and groundwater is missing in most countries.

PFAS in drinking water in India

PFAS in drinking water is an emerging environmental and public health concern in India, and information on concentrations in drinking water, including surface and groundwater, is limited. As part of the INOPOL project, an overview of PFAS status in drinking water in India was published (Roy-Basu et al., 2025). In India, limited but growing detection of PFAS in drinking-water sources is evident across urban and river-basin settings. A review under the INOPOL project (2025) reports that tap-water studies from Goa, Coimbatore and Chennai analysed a limited number of samples (tens of samples) and detected seven PFAS, with concentrations reaching up to 81 ng/L for compounds such as PFHxS in 2009. In the Ganga River basin (2016), covering multiple surface- and groundwater samples used for drinking, a reported detection of up to 15 PFAS, typically in the range of <1 to 10 ng/L. In Chennai, Tamil Nadu (2024), the analysis of surface water, groundwater, and treated drinking water samples revealed a wider range of PFAS concentrations, from 0.1 ng/L to 136 ng/L, with both short-chain PFAS (e.g., PFBS) and legacy compounds such as PFOA being frequently detected (Roy-Basu et al., 2025).

This report explores the presence and management

of PFAS in India's drinking water systems. It details how these persistent chemicals originate from industrial discharges, firefighting foams, and consumer products, eventually accumulating in water sources and human bodies. The sources highlight significant public health risks, including links to cancer, reproductive issues, and impaired immunity, while noting that vulnerable communities are at the highest risk. A critical analysis reveals that India currently lacks robust regulatory frameworks and comprehensive monitoring networks compared to North America and Europe.

Consequently, the report proposes policy recommendations such as establishing national safety limits, investing in advanced water treatment technologies, and launching a nationwide contamination map. Ultimately, the authors advocate for multisectoral collaboration and increased public awareness to safeguard India's water quality and ensure environmental justice.

The urgent need for stronger regulations, monitoring systems, increasing public and stakeholder awareness, and informed policymaking to mitigate the growing threat of PFAS contamination in India is in accordance with findings from Gautam et al. (2025).

2.5 Alternatives to POPs

The global move towards eliminating POPs under the Stockholm Convention has encouraged countries, including India, to adopt safer and sustainable chemical alternatives. The identification, evaluation, and promotion of these substitutes are essential for reducing environmental and human health risks while maintaining industrial productivity. Effective substitution requires a lifecycle approach, considering not only chemical toxicity but also performance, cost-effectiveness, and end-of-life management.

Pesticide alternatives

In the agricultural sector, a gradual phase-out

of organochlorine pesticides such as DDT, aldrin, and endosulfan has led to the adoption of less persistent and biodegradable options. Integrated pest management, biopesticides, and botanical formulations derived from neem (*Azadirachta indica*) and other natural sources have gained prominence. The use of microbial pesticides, pheromone traps, and biological control agents is being promoted under national programs such as the National Mission on Sustainable Agriculture and the *Rashtriya Krishi Vikas Yojana*. These actions have been highly effective at reducing localised pesticide intensity (by approximately 30–60%) but have not yet reached the scale required to reverse the total national volume of chemical pesticide consumption. These strategies can not only minimise the need for chemical pesticides but also improve soil health and biodiversity.

Industrial and manufacturing alternatives

For industrial POPs like PCBs, phase-out programs have led to the replacement of PCB-based transformers and capacitors with non-chlorinated dielectric fluids such as mineral oils, silicone oils, and synthetic esters. Similarly, cleaner production technologies and energy-efficient processes are being introduced to reduce unintentional releases of dioxins and furans during combustion and metal processing. The adoption of Best Available Techniques (BAT) and Best Environmental Practices (BEP) in the NIP for India has been promoted through guidelines under the Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2025.

Alternatives to flame retardants and PFAS

Brominated Flame Retardants such as penta-BDE, octa-BDE, and hexabromocyclododecane have been effectively banned and mandated to be replaced. Safer organophosphorus compounds, nitrogen-based flame retardants, and mineral fillers such

as aluminium hydroxide and magnesium hydroxide offer substitutes that are effective in fire resistance while avoiding persistence and bioaccumulation in the environment. In textile, paper, and coating applications, the gradual transition away from PFAS-based repellents is gaining momentum. Fluorine-free alternatives, including silicone-based and hydrocarbon-based repellents, are being adopted by leading manufacturers to meet global standards such as the EU REACH regulations and the Zero Discharge of Hazardous Chemicals framework, including Zero Liquid Discharge norms in the Indian context.

Waste management and emission control

To curb unintentional POP generation from waste incineration and open burning, emphasis is being placed on waste minimisation, segregation, and use of advanced incineration technologies with continuous emission monitoring systems. The promotion of co-processing of non-recyclable plastics in cement kilns under controlled conditions serves as an environmentally sound alternative to uncontrolled combustion. Cleaner technologies for electronic waste recycling, such as mechanical dismantling, closed-loop smelting, and plasma arc treatment, are critical for the prevention of secondary releases of halogenated POPs.

Policy and capacity-building implications

Identifying and scaling up POP-free alternatives requires collaboration between regulatory authorities, industry, and research institutions. The Ministry of Environment, Forest and Climate Change (MoEF&CC), in coordination with the Bureau of Indian Standards (BIS), is encouraging the development of eco-labelling and certification schemes to promote environmentally friendly products. Research institutions under CSIR (Council of Scientific and Industrial Research) and academic partners are developing analytical methods and pilot

testing green substitutes for industrial chemicals. Incentivising cleaner production through financial mechanisms such as green procurement, tax rebates, and technology transfers can also accelerate POPs substitutions.

2.6 International, national, state policies and regulations

POPs are recognised as a global environmental threat requiring coordinated international action. India's engagement in global conventions forms the backbone of its national POPs management policy. The Stockholm Convention on Persistent Organic Pollutants (2001) remains the most significant treaty, aiming to eliminate or restrict the production and use of POPs. India ratified the Convention on 13 January 2006, adopting an "opt-out" clause to ensure that future amendments to the annexes are ratified only after due national review. The Convention initially targeted the "dirty dozen" POPs and has since expanded to regulate 34 chemicals. In addition to ratifying the original dirty dozen, India has ratified seven additional POPs, including hexabromocyclododecane (HBCD), pentachlorobenzene (PeCB), pentabromodiphenyl ether, octabromodiphenyl ether, hexabromobiphenyl, lindane, and perfluorooctane sulfonic acid (PFOS). However, India currently maintains an opt-out status or specific exemptions for several other POPs, notably chlorpyrifos, polybrominated diphenyl ethers (PBDEs) under certain uses, and other recently listed fluorinated and brominated compounds.

Complementary international instruments further support POPs management. The Basel Convention (1989) governs the transboundary movement and disposal of hazardous wastes, including POPs, and promotes environmentally sound waste management. The Rotterdam Convention (1998) provides the Prior Informed Consent (PIC) mechanism to regulate international trade in hazardous chemicals and pesticides. Regionally,

the Aarhus Protocol on POPs (1998) under the UNECE's Convention on Long-Range Transboundary Air Pollution (LRTAP) limits emissions of POPs across Europe and North America, providing a framework for global best practices. The Strategic Approach to International Chemicals Management (SAICM, 2006) complements these legally binding instruments through voluntary commitments for sound chemicals management across the lifecycle.

Globally, the European Union's POPs Regulation (EU 2019/1021) and REACH Regulation (EC 1907/2006) represent stringent regional frameworks aligned with the Stockholm Convention. These instruments focus on the restriction, monitoring, and safe disposal of POPs while promoting sustainable alternatives. International support mechanisms, such as the Global Environment Facility (GEF) and the UNEP Special Programme on Chemicals and Waste, provide technical and financial assistance to developing countries, including India, for strengthening institutional capacities, developing NIPs, and promoting BAT and BEP.

National regulatory framework in India

India's commitment to addressing POPs is grounded in its constitutional and legislative mandates. Article 48A and Article 51A of the Constitution enjoin the State and citizens to protect and improve the environment, while judicial interpretation under Article 21 has extended the right to life to include the right to a healthy environment.

The Environment (Protection) Act, 1986, serves as the umbrella legislation, under which multiple rules regulate hazardous chemicals and waste. Key subordinate legislations include the Manufacture, Storage and Import of Hazardous Chemical Rules, 1989; the Chemical Accidents (Emergency Planning, Preparedness and Response) Rules, 1996; the Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016; and the Solid Waste Management Rules, 2016. The

Insecticides Act, 1968, governs pesticidal POPs, while the Biomedical Waste Management Rules, 2016 and the E-Waste (Management) Rules, 2016 provide additional controls for unintentional POPs such as dioxins, furans, and brominated flame retardants.

In alignment with the Stockholm Convention, India notified the Regulation of Polychlorinated Biphenyls (PCBs) Order, 2016 and the Regulation of Persistent Organic Pollutants Rules, 2018, which prohibit the manufacture, import, and use of seven POPs, including hexachlorobenzene and pentachlorobenzene. The 2018 Rules marked a significant advancement in aligning national regulation with global standards. Additionally, the Union Cabinet ratified seven more POPs under the Stockholm Convention in October 2020, reinforcing India's ongoing commitment to phased elimination.

India's NIP, first published in 2011, provided a comprehensive strategy for managing the initial twelve POPs through short-, medium-, and long-term measures. The NIP identified priorities including PCB disposal, medical waste management, non-POPs alternatives to DDT, and capacity building for monitoring and inventory management. India is presently updating its NIP to incorporate newly listed POPs and strengthen monitoring mechanisms. The MoEF&CC serves as the nodal ministry, supported by institutions such as the CPCB, State Pollution Control Boards (SPCBs), and research bodies like the CSIR-National Environmental Engineering Research Institute, the CSIR-Indian Institute of Toxicological Research, and the National Accreditation Board for Testing and Calibration Laboratories (NABL).

Institutional mechanisms and programmes

India has implemented several international and nationally funded projects for POPs management, primarily through collaboration with the Global Environment Facility, the United

Nations Environment Programme, and the United Nations Industrial Development Organisation. Notable initiatives include the Environmentally Sound Management and Final Disposal of PCBs in India (2009–2013), Environmentally Sound Management of Medical Wastes (2011–2016), and the Development and Promotion of Non-POPs Alternatives to DDT (2015–2022). These initiatives strengthened institutional capacity, introduced alternative pest control strategies, and established pilot facilities for POPs destruction and dechlorination.

The MoEF&CC, in coordination with CSIR-NEERI, is currently implementing a GEF-supported project (2022–2025) to review and update the NIP. The project seeks to address infrastructure and data gaps, build analytical capacity for newly identified POPs, and enhance coordination among central and state agencies. Moreover, the Biomedical Waste Management Rules (2019) have integrated stringent emission norms for dioxins and furans, adopting BAT and BEP.

Implementation challenges

Despite comprehensive legislation, India faces persistent challenges in enforcement, data management, and institutional coordination. Fragmented mandates across ministries such as environment, agriculture, and health, create overlaps and hinder integrated chemical management. Limited laboratory infrastructure and analytical capacity constrain routine monitoring of industrial POPs. Many state agencies and urban local bodies lack resources for safe waste segregation and disposal, leading to unintentional POP releases from open burning and informal recycling.

To strengthen implementation, important interventions to bridge data gaps include building a robust monitoring network, expanding accredited laboratories, and integrating POPs monitoring into existing pollution control programmes. Financial mechanisms, including earmarked funds need to

support state-level implementation. Capacity building at all levels, especially among SPCBs, customs officials, and industries, is essential to improve compliance and surveillance.

Regular NIP updates, transparent data dissemination, and regional cooperation with South Asian partners will be vital to achieving sustainable management of POPs and aligning India's regulatory framework with global best practices.

India is confronting the dual burden of legacy POPs from past practices and a new generation of POPs that are more mobile, harder to treat, and often poorly characterised in monitoring programmes. Despite significant regulatory advances, gaps in

enforcement, analytical capacity, and coordinated surveillance allow POPs to persist in the air, water, soil, and biota, which leads to documented human exposure through food, drinking water, and occupational settings. The growing evidence reinforces the urgency of strengthening regulations, scaling up POPs-free alternatives, and investing in monitoring and treatment infrastructure that prioritise vulnerable communities. By framing these scientific, technological, and policy needs within an Indian context, this chapter serves as the analytical foundation for the next chapters, which propose targeted interventions, evaluate management options, and support more protective, equity-oriented chemicals governance in the country.





Chapter 3

DISTRIBUTION, SEASONAL VARIATION, AND COMPARISON OF POPS IN SURFACE WATER AND SEDIMENT FROM CAUVERY RIVER, TAMIL NADU

This chapter investigates the spatial distribution, seasonal variation, and sources of legacy and emerging POPs in the surface water and sediments along the Cauvery River and its tributaries in Tamil Nadu, with a particular focus on industrial and open-burning hotspots in the Noyyal–Trichy–downstream corridor. By jointly analysing PFAS, PBDEs, HBCD, and organochlorine pesticides during contrasting hydrological conditions, the chapter provides a comprehensive picture of how riverine hydrodynamics, land use, and waste management practices shape contaminant profiles and ecological risks across upstream, midstream, and downstream reaches. By linking concentration patterns with ecotoxicological risk quotients, atmospheric transport, and plastic–POPs interlinkages, the chapter establishes the Cauvery system as a sensitive receptor of mixed anthropogenic pressures and provides an empirical basis for identifying priority hotspots and exposure pathways in southern India.

This is the first attempt to report the spatial distribution of new and legacy POPs during dry and wet seasons along the upstream, midstream, and downstream of the Cauvery riverine environment in Tamil Nadu. Furthermore, we identified potential sources and hotspot regions and assessed the potential ecotoxicological risk. Finally, we have highlighted that hotspots exhibit evidence of surface run-off of POPs linked with the open burning of dumped plastic waste.

3.1 Identification of pollution hotspots exhibit evidence of surface runoff of POPs

Three major categories of POPs, namely PFAS, brominated flame retardants, and organochlorine pesticides, have been investigated during the dry season (March 2024) and the wet season (November 2024) along the Cauvery River (Figure 3.1), which flows through Tamil Nadu to the meeting point in the Bay of Bengal. The ecotoxicological risk assessment was performed according to USEPA (1998) guidelines. The same risk calculation approach was applied in other studies (Rex and Chakraborty, 2022; Riaz et al., 2023).

3.1a. Per- and polyfluoroalkyl substances (PFAS)

PFAS may be classified according to carbon chain length, like short-chain perfluoroalkylcarboxylic acids (SC-PFCA, $C \leq 6$) and short-chain perfluoroalkylsulfonic acids (SC-PFSA), as well as long-chain perfluoroalkylcarboxylic acids (LC-PFCA, $C \geq 7$) and long-chain perfluoroalkylsulfonic acids (LC-PFSA) (Buck et al., 2011). The average concentration of SC-PFCA was higher than that of LC-PFCA; similarly, SC-PFSA was higher than that of LC-PFSA (Figure 3.2). This most likely reflects the ongoing industrial shift from LC to SC-PFAS or the higher mobility of SC-PFAS compared to LC-PFAS



Figure 3.1: Figure 3.1a: Schematic representation of activities in the catchment associated with targeted POPs and Figure 3.1b. Sources along the Cauvery River Basin in Tamil Nadu

from the catchment (Shaffer et al., 2025). Indian rivers showed similar patterns, with dominance of SC-PFCAs over LC-PFCAs in the Ganges (Sharma et al., 2016), Cauvery, and Tamirabarani Rivers (Selvaraj et al., 2021). The box plots represent the range of concentration of SC-PFCA, LC-PFCA, SC-PFSA, and LC-PFSA in the surface water of the Cauvery River (Figure 3.2). The average concentration of Σ_{25} PFAS in the Cauvery River is 35 ng/L in the wet season, which is somewhat higher compared to the dry season (25 ng/L). Higher PFAS levels during the wet season can be attributed to increased surface runoff, primarily in downstream (DS) and upstream (US) regions where industrial and open-burning activities are prevalent. The highest average PFAS concentrations of around 50 ng/L and 60 ng/L, respectively, were found across all sites in Trichy and the Noyyal River in both dry and wet seasons.

Effluents from wastewater treatment plants and landfill leachates are significant contributors to PFOA and PFOS contamination (Xiao, 2022). The sites in the Noyyal River (NR) cover the industrial region with textile industries (Babu et al., 2017). Direct discharge points from textile industries were also observed in those industrial regions. Domestic sewage and effluent from wastewater treatment plants are also identified as significant contributors of PFAS to surface waters (Clara et al., 2008). NR is a tributary that flows only during the wet season

and joins the Cauvery mainstream during that time, which could also contribute to the elevated PFAS concentrations observed during the wet season. Open burning is practised along the river sampling sites in Trichy. PFAS originating in such urban waste disposal sites might have been released from dumped personal care products, cookware, automotive materials, furniture, and construction materials via leachate and contaminated surface water systems (Paige et al., 2024). Our measured average concentrations in ng/L of PFAS from industrial and open burning sites are higher than the studies from the Brisbane River (40 ng/L) of Australia (Gallen et al., 2014), the Ganges River (15.9 ng/L) (Sharma et al., 2016) of India and slightly lower than the Swedish rivers (60 ng/L) (Nguyen et al., 2017) of Europe and the Pearl River Delta (1400 ng/L) of China (Bian et al., 2024) and within the range of the Jiulong River Estuary (3.3–110 ng/L) (Cai et al., 2018) of China.

The Cauvery River is a significant source of drinking water and irrigation for Tamil Nadu (TNPCCB, 2018). The PFOS levels at 16 sites in the Cauvery River during the dry season and 14 sites during the wet season exceeded the European Union (EU) Environmental Quality Standard (EQS) of 0.65 ng/L for inland surface waters (Water Framework Directive, European Commission, 2008). The USEPA Maximum Contaminant Level (MCL) of 4 ng/L

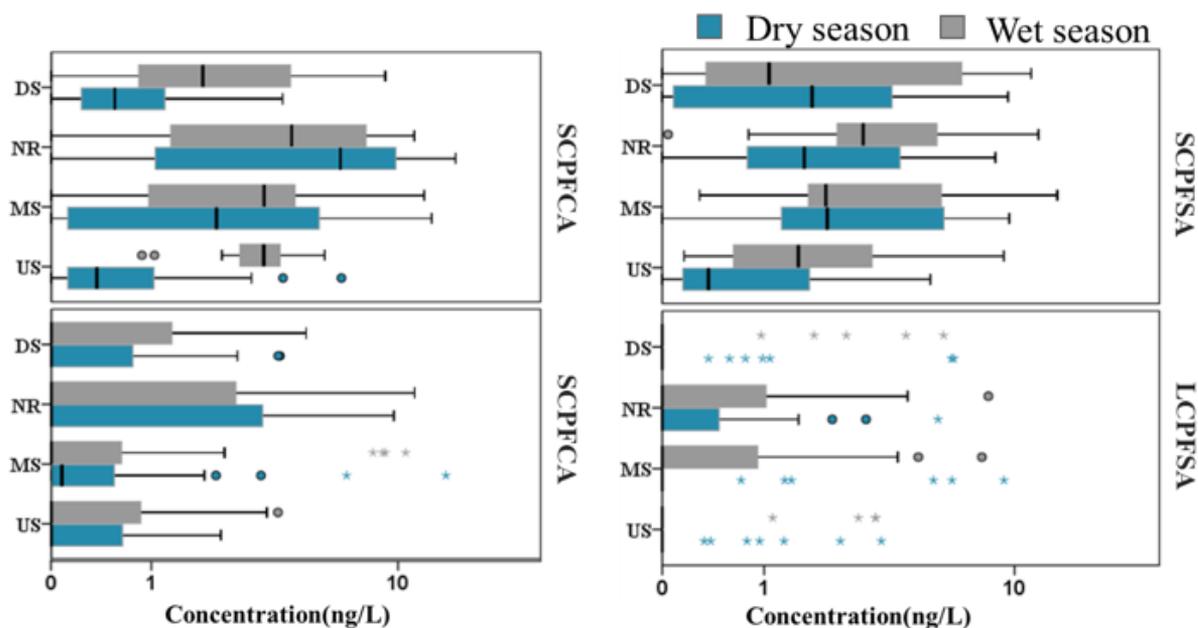


Figure 3.2: Box plots showing the concentration of SC-PFCA ($C \leq 6$), LC-PFCA ($C \geq 7$), SC-PFSA, and LC-PFSA in the Upstream (US), Midstream (MS), Noyyal River (NR), and Downstream (DS) surface water of Cauvery River. (• = mild outlier ($1.5-3 \times IQR$), * = extreme outlier ($>3 \times IQR$))

(USEPA, 2024) was exceeded for PFOA and PFOS at specific industrial and open-burning sites.

3.1b. Polybrominated Diphenyl Ethers (PBDEs)

PBDE levels in the surface water of the Cauvery River and its tributaries showed marked seasonal variations, most likely due to hydrological conditions and the compounds' physicochemical behaviours. In surface water (Figure 3.3), the average concentration of \sum_{27} PBDE in the Cauvery River is higher during the dry season (20 ng/L) than the wet season (11 ng/L), most likely due to dilution during the wet season (Xie et al. 2024). Regardless of the season, sites near the open burning of dumped waste in the cities of Trichy and Thanjavur exhibited higher average total PBDE levels, up to 50 ng/L. In contrast, the combined average across the remaining sites was around 10 ng/L (Figure 3.3). The dry season was dominated by higher brominated homologues, such as nona-

and octa-BDEs, indicating inputs from technical deca-BDE formulations commonly associated with e-waste and polymer residues (Kostenko et al., 2024). A similar dominance of heavier congeners was also observed in surface water from rivers in China and Taiwan recently, where human and industrial activities were identified as the primary sources (Pei et al., 2018; Trinh et al., 2019). These increased concentrations of heavier congeners can also be potentially driven by the desorption of these compounds from the sediment matrix to the aqueous phase under low-flow or dry-season conditions. During the low-flow dry season, reduced water volume, increased exposure of sediment to sunlight, and enhanced decomposition of organic matter weaken sediment binding capacity, thereby promoting the release of PBDEs into the overlying water (Li et al., 2024). The accumulation of heavier PBDE congeners, particularly Deca-BDE and BDE-209, in sediments is making them a long-term sink. Photodegradation of higher-brominated PBDEs into more soluble, mobile congeners further accelerates

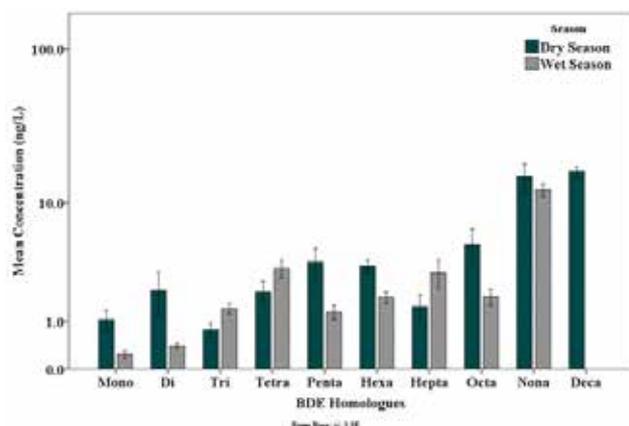


Figure 3.3: Mean concentration (ng/L) of PBDE homologues in surface water during dry and wet seasons in Cauvery River, Tamil Nadu (in log scale)

their desorption from sediments during this period (Pan et al., 2016). The wet season showed a relative increase in the proportion of lower brominated homologues, such as tri- and tetra-BDEs, which have higher water solubility and are most likely impacted by surface runoff. Compared with worldwide studies, the levels of PBDEs in this study are comparable to those in the Yellow River in China (Pei et al., 2018), the Sundays Estuary in South Africa (Olisah et al., 2020), and the Chenab River in Pakistan (Mahmood et al., 2015). However, the Guanlan River from China

(58.40 - 186.35 ng/L) (Liang et al., 2019) and the Nahoon River estuary of South Africa (25.32–785 ng/L) (Ohoro et al., 2022) showed PBDE levels much higher in surface water than the Cauvery River.

3.1c. Hexabromocyclododecane (HBCD)

In the surface water of the Cauvery River, HBCD concentrations showed distinct seasonal variation and congener dominance. During the dry season, α -HBCD exhibited the highest concentrations, averaging 19 ng/L in the industrial regions of NR, whereas concentrations were less than 1 ng/L at the remaining sites. In contrast, during the wet season, α -HBCD concentrations declined sharply (average 0.70 ng/L). In most global studies, γ -HBCD dominates due to its high proportion (≈ 75 – 89%) in commercial formulations. The dominance and elevated levels of α -HBCD at industrial sites along the NR are consistent with those observed in industrialised regions of China, Japan, and South Korea (Heeb et al., 2008). Elevated levels of α -HBCD in the industrial areas along the NR most likely resulted from γ -HBCD transformation during the industrial processes into the more thermodynamically stable α -HBCD (Zhao et al., 2010).

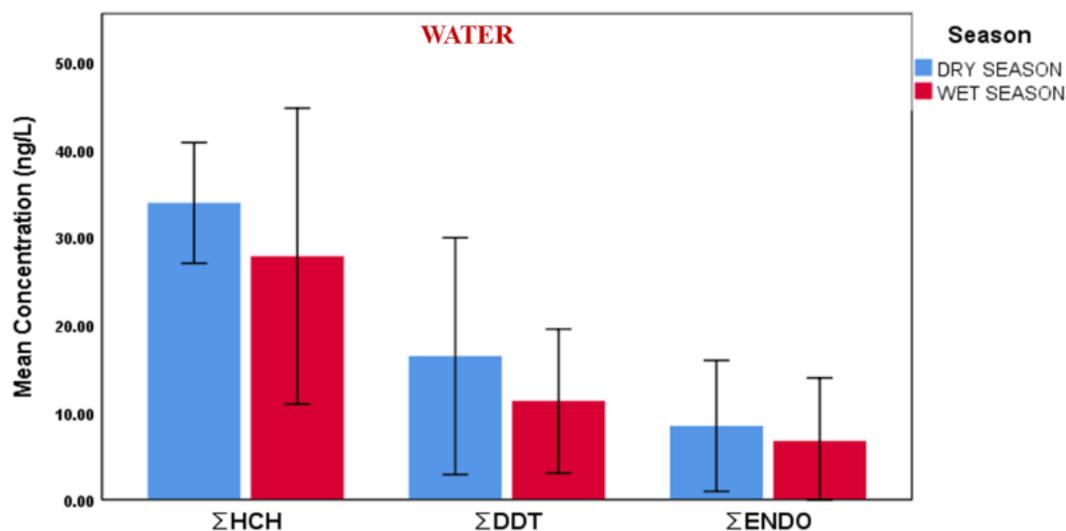


Figure 3.4: Error plots showing the average concentration of HCH, DDT and endosulfan along the Cauvery Riverine region of Tamil Nadu

When compared globally, the Cauvery River shows moderate contamination. It is far below the extremely high concentrations reported in East Asian rivers such as the Southern coast of Weifang City, Shandong Province, in China (up to 2,541.64 ng/L) (Zhang et al., 2018) and those in Japan, the Kuzuryu River (1,140 ng/L) (Oh et al., 2014) and South Korea (as high as 75.6 ng/L) (Jo et al., 2017). Rivers like the Lower Yangtze River in China and rivers in England exhibit lower levels (around 2.145 ng/L) (Harrad et al., 2009; Zhang et al., 2022).

3.1.d. Organochlorine pesticides (OCPs)

The Cauvery River showed extensive contamination by both newly listed and legacy pesticidal POPs. Both new POPs, such as Σ HCH, Σ Endosulfan, and methoxychlor, and legacy POPs, such as Σ DDT, Σ Chlordane, and Σ Endrin, were regularly detected in all the samples. The sum of HCH showed elevated levels in the Cauvery River catchment compared to Σ DDT and Σ ENDO in both dry and wet seasons (Figure 3.4). There is a noticeable change in the composition of all detected OCPs from the dry season to the wet season, indicating seasonal influences on the temporal variation of OCPs. In the water samples, compounds such as γ -HCH and p,p' -DDE appear to be present in significant amounts at several sites, both during the dry and wet seasons. The presence of α -HCH and α -Endosulfan is also notable but varies between seasons and across sites. High concentrations of Σ DDT and Σ HCH, especially at the downstream sites, most likely resulted from the surface run-off of the agricultural fields in addition to vector control programs. In the sediment samples, Σ HCH and Σ DDT concentrations were recorded up to 24 ng/g and 8.3 ng/g, respectively, in the downstream sites. Along the Cauvery River, α/γ -HCH >1 at most locations reflects ongoing use of technical formulation. The HCH concentration range is comparable with other Indian riverine sediments (Khuman et al., 2020). This level, on the other hand, is much lower than the level in the Ravi River in

Pakistan (Σ HCH = 27.82 \pm 46.69 ng/g) (Baqar et al., 2018).

3.2 Interlinkages between POPs and plastics

Synthetic polymers/plastics and POPs share certain traits, such as persistence, resistance to biological degradation, and the ability to be transported over long distances. A cocktail of POPs linked with plastics from different waste streams is released, particularly during open burning in India (Chakraborty et al., 2022). POPs, such as PBDEs, are widely used as flame retardants in commercial foams used to make domestic products and in the plastic casings of electronic gadgets, and they may end up in recycled plastic products (Kajiwara et al., 2022). PFAS incorporated into plastic-based personal care packaging, non-stick cookware coatings, furniture treatments, and construction materials can leach out as these plastic products degrade in landfills, subsequently contaminating surrounding water bodies (Paige et al., 2024). Throughout production, consumption, and disposal, plastics interact with and accumulate POPs through several mechanisms, thereby coexisting with them in the environment.

The Noyyal River, a tributary of the Cauvery River, is surrounded by industrial areas and direct discharges from open drains, where the concentration is highest for the sum of quantified and detected PFAS and flame retardants (PBDEs and HBCD). The midstream covered Trichy city, where open drains and open burning of dumped domestic wastes are prevalent. Higher levels of plastic additives such as phthalic acid esters have been observed in these sites in the recent past and attributed to open burning of dumped plastic wastes (Chandra and Chakraborty, 2024). Moreover, POPs used in various plastic products and electronic gadgets are released during incomplete combustion of the dumped waste (Chakraborty et al., 2022; Chakraborty et al., 2023; Chakraborty et

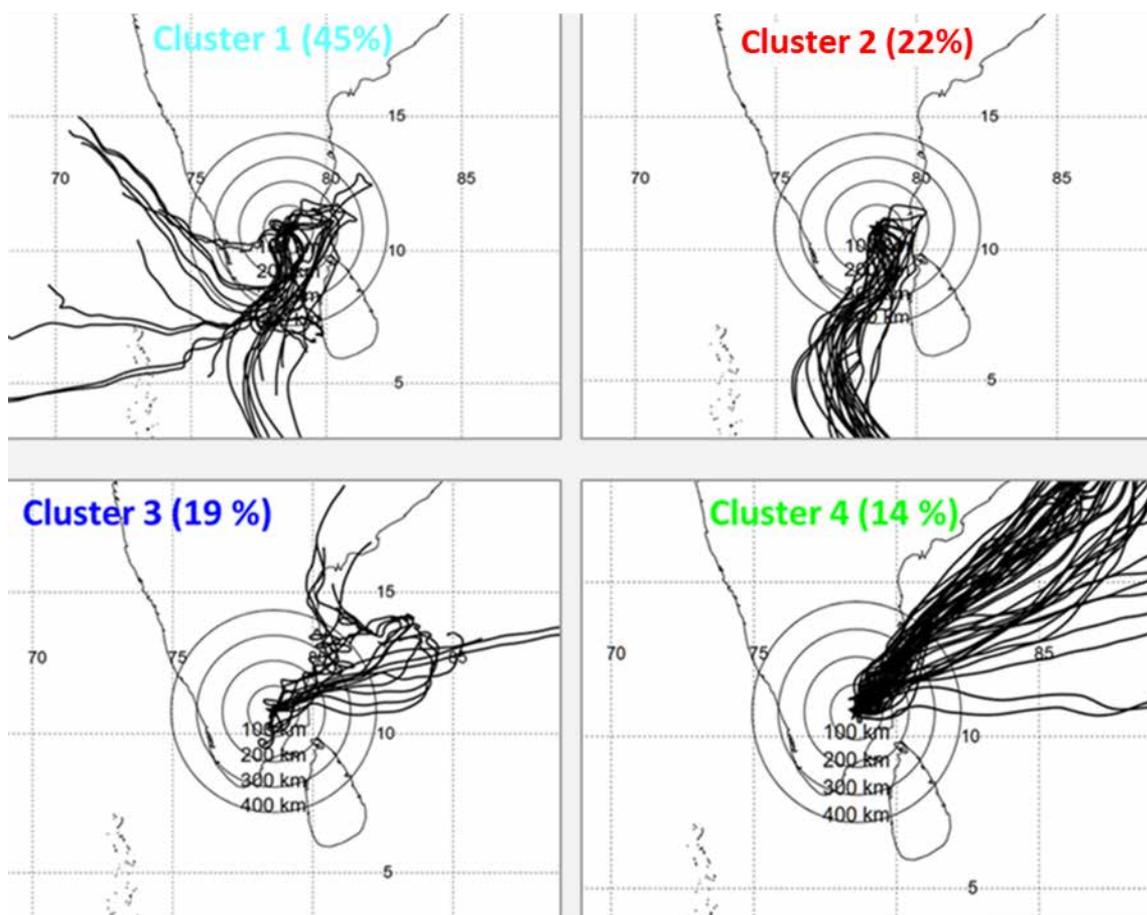


Figure 3.5: Five-day average air-mass back-trajectories showing a cleansing effect along the Cauvery River

al., 2025). Open burning sites are localised hotspots for the emission of a cocktail of hazardous organic chemicals (Chakraborty et al., 2021). Net air-water exchange fluxes for PBDEs along the Cauvery River showed atmospheric emission of not only tetra- and penta homologue BDEs but also some of the heavier ones like BDE-154 and -153, which are having a significant contribution in commercial Octa-BDE formulations like DE-79 and Bromkal 79-8DE (USEPA 2006; 2008). These technical formulations are mainly used as additive flame retardants in plastics for electrical and electronic equipment (La Guardia et al., 2006).

The atmospheric air mass cleansing effect due to all ocean-based air mass clusters traversing in Tamil Nadu during the wet season due to the retreating

monsoon was evident. We found four distinct air mass clusters originating from the Indian Ocean (Cluster 1, 45% and Cluster 2, 22%) and the Bay of Bengal (Cluster 3, 19% and Cluster 4, 14%) before ending in the sampling sites along the Cauvery River of Tamil Nadu during the atmospheric sampling period (Figure 3.5). However, elevated atmospheric PBDE concentrations in Trichy reflect such localised point sources due to open burning of dumped waste containing different types of end-of-life plastic products and packaging materials. Moreover, the hydrophobic and particle-bound nature of PBDEs favours their adsorption onto suspended solids and subsequent deposition into sediments (Ohoro et al., 2021). The presence of approximately 70% heavier BDE homologues in sediment in such hotspot areas indicate a substantial contribution from particle-

associated PBDEs transported by runoff from open-burning sites.

The investigated POPs, viz., PFAS, PBDEs, HBCDs, and OCPs, were higher in the wet season compared to the dry season, possibly due to surface run-off and atmospheric deposition of semi-volatile POPs. Hotspots included open burning and industrial sites with levels differing by 3- to 5-fold relative to the upstream and downstream regions. It is evident that the open burning of dumped waste plastics, particularly in Trichy, resulted in the emission of high levels of PBDEs.

The findings from Chapter 3 demonstrate that distinct hotspots near industrial clusters, open drains, and open-burning sites exhibit consistently elevated levels of PFAS, PBDEs, HBCD, and OCPs, which were often severalfold higher than nearby upstream and downstream segments. This finding demonstrates the need for localised interventions at these source zones. Seasonal contrasts, with higher PFAS and several pesticidal POPs during the wet season and pronounced enrichment of heavier PBDE and HBCD congeners in the dry season, underline the critical role of the Indian monsoon and its ability to affect surface runoff, atmospheric deposition and sediment–water exchange in governing contaminant dynamics along the Cauvery River. The documented coupling between plastics and POPs, particularly at the Noyyal–Trichy openburning and discharge sites, indicates that unmanaged plastic waste streams and informal waste practices act as key vectors for both legacy and new POPs to enter aquatic and atmospheric compartments in the Cauvery deltaic region. Collectively, these insights position the Cauvery as a critical case study for riverine POPs management in India and point towards targeted control of open burning, improved wastewater and leachate treatment, and stricter regulation of POP-containing products and plastic waste flows in identified hotspot regions.

3.3 Gendered health impacts of POPs

POPs management in India is gendered, shaped by the interaction of biological vulnerability and socially structured patterns of work, consumption, and care (Plassnig et al., 2025). Women are disproportionately affected by POPs across multiple stages of the plastics lifecycle due to hormonally sensitive physiological processes, gendered exposure pathways, and structural inequalities that limit their access to protection, healthcare, and decision-making power (Lynn et al., 2017; Messing et al., 2003; Plassnig et al., 2025). This sub-chapter summarises the gendered health impacts of POPs exposure, drawing on evidence collated in the report *Gender dimensions of plastic and POPs pollution in India: Tracing impacts across the plastics value chain* developed under the INOPOL project (Plassnig et al., 2025).

From a biological perspective, women experience heightened susceptibility to POPs because many of these chemicals are lipophilic and accumulate in body fat, which women typically have in higher proportion than men (Messing et al., 2003; Tran & Miyake, 2019). Vulnerability is further intensified during hormonally active life stages such as puberty, menstruation, pregnancy, lactation, and menopause, when endocrine-disrupting chemicals can interfere with reproductive and metabolic processes (Lynn et al., 2017; Plassnig et al., 2025). Scientific evidence links POPs exposure to infertility, uterine fibroids, recurrent miscarriages, shortened lactation, and breast cancer, as well as health risks such as diabetes, obesity, cardiovascular disease, and hormone-related cancers (Lynn et al., 2017; Tran & Miyake, 2019).

Maternal transfer is a critical gendered exposure pathway, where POPs are passed from pregnant women to foetuses through the placenta and later through breast milk during lactation (Tran & Miyake, 2019; Shelke, 2024; Plassnig et al., 2025). This

route is particularly concerning because infants and young children have lower body weight and underdeveloped detoxification systems, making them highly vulnerable to toxic effects (Smithers, 2023; Li et al., 2023). In India, elevated levels of PFAS have been detected in breast milk samples from women in Chidambaram and Chennai, exceeding health advisory limits previously set in the United States (Roy-Basu et al., 2025; Tao et al., 2008). Furans, dioxins, PCBs, and organochlorine pesticides have similarly been identified in breast milk samples near open dumping sites in Chennai and Kolkata, underscoring the intergenerational nature of POPs exposure (Someya et al., 2010; Plassnig et al., 2025).

Beyond biological vulnerability, women's socially structured roles create distinct exposure profiles. Women are more likely to encounter POPs through daily use of cleaning agents, cosmetics, personal care products, and household plastics, products that are often heavily plastic-based and contain endocrine-disrupting additives such as phthalates and bisphenols (Rumph et al., 2022; Liao et al., 2018; Plassnig et al., 2025). Higher concentrations of phthalates have consistently been found in women's bodies compared to men, raising concerns about reproductive health, foetal development, and long-term disease risk (Liao et al., 2018; Landrigan et al., 2023).

Menstrual products represent a particularly under-researched but potentially significant exposure route. Tampons and sanitary pads contain large proportions of plastic, and recent laboratory studies have detected synthetic polymers, lead and nanoplastics released during use (Munoz et al., 2022; Lynn et al., 2017; Shearston et al., 2024). With women using menstrual products an estimated 11,000 times over their lifetime, repeated mucosal exposure to plastic particles and associated chemical additives may pose cumulative health risks, although robust epidemiological evidence remains limited (Upson et al., 2022; Plassnig et al., 2025).

Women working in plastics manufacturing, recycling, and informal waste management face prolonged

contact with hazardous chemicals, including Bisphenol A (BPA), phthalates, and monomers such as vinyl chloride and styrene, as well as flame retardants, some of which are classified as POPs, and other toxic substances such as benzene (Engel & Rasanayagam, 2015; Shen et al., 2022; Plassnig et al., 2025). Yet many of these chronic condition's manifest years after exposure, meaning they are often excluded from occupational health statistics and disease burden estimates (Lynn et al., 2017).

Environmental exposure also follows gendered spatial patterns. Women living near industrial zones, informal dumping sites, and poorly managed waste facilities experience elevated exposure through contaminated air, soil, water, and food (Caterbow & Hausmann, 2016; Lynn et al., 2017). POPs accumulate through the food chain, particularly in fatty foods such as fish, meat, eggs, and dairy, posing consistent dietary exposure risks in polluted regions (Guo et al., 2019; Barot & Kumar, 2021; Shelke, 2024). Microplastics further act as vectors for POPs, entering the body through ingestion, inhalation, and absorption through skin contact, and have been detected in drinking water, milk, sugar, salt, tea, and seafood (Cox et al., 2019; Kuttralam-Muniasamy et al., 2020; Vega-Herrera et al., 2022).

Importantly, structural inequalities compound gendered health impacts (Plassnig et al. 2025). Women from disadvantaged socioeconomic backgrounds are more likely to work in unregulated and hazardous environments, have limited agency over workplace safety, and face barriers to healthcare access (Krishnan & Backer, 2019; Sahu & Behera, 2023). When experiencing illness, many women in precarious situations cannot afford to seek medical treatment due to loss of daily income, resulting in untreated and chronic conditions (Wittmer, 2020; Mote, 2016).

POPs exposure in India produces cumulative, intergenerational, and structurally embedded health burdens for women (Plassnig et al. 2025). These burdens arise not only from biological sensitivity but

also from gendered divisions of labour, consumption practices, environmental proximity, and systemic gaps in occupational protection and public health governance (Plassnig et al., 2025).

Effective responses to POPs-related health harms depend on gender-responsive health monitoring, strengthened enforcement of occupational health and safety standards, targeted protection for pregnant and nursing women, systematic integration of gender

consideration across plastics- and chemicals-related policy frameworks, greater awareness among policymakers and the wider Indian population of the gendered dimensions of POPs-related hazards, and the meaningful participation of women stakeholders at all levels in the design, implementation and evaluation of existing and future POPs-related policies and action plans.



Chapter 4

KEY CHALLENGES AND OPPORTUNITIES

The expansion of the industrial base and modernisation of agriculture in Tamil Nadu have added to the load of POPs in soil and water bodies and have impacted the food chain. This chapter analyses the significant barriers that enable POPs to remain in the environment and the potential strategies through which the state could enhance its response. It outlines the regulatory and institutional challenges, the impact of international conventions on local obligations, and the opportunities, such as scientific capability, administrative structures, and engaged stakeholder networks, that can propel the state towards a preventive strategy for managing POPs.

4.1 Pollution, trade risks and governance gaps

POPs, which include legacy pesticides like DDT and HCH as well as industrial compounds such as PCBs, are notorious for their persistence in the environment, ability to bioaccumulate in living organisms, and toxic effects even at very low concentrations. Tamil Nadu's rapid industrialisation and urbanisation have made it a hotspot for POPs contamination, particularly in river basins such as the Cauvery, Adyar, and Cooum (Akhil & Sujatha, 2014; Government of Tamil Nadu, n.d.). Scientific studies have revealed that the Adyar and Cooum rivers in Chennai detect high levels of DDT, HCH, endosulfan, and PCBs, with the situation worsening during monsoons due to increased surface runoff and atmospheric deposition (Akhil & Sujatha, 2014).

The Tamil Nadu Pollution Control Board (TNPCB) has reported elevated levels of chemical and

organic pollution in river water samples (DT Next, 2022). Another growing concern is the link between plastic pollution and POPs. Plastics can adsorb POPs from the environment and release them when burnt or degraded. This was evident during the COVID-19 pandemic, when increased open burning and surface runoff led to a dramatic spike in PCB-52 levels in Chennai's rivers (Rex and Chakraborty 2022). The persistence and bioaccumulation of POPs result in their accumulation in sediments and aquatic organisms, entering the food chain and posing long-term risks to both ecosystems and human populations. Fish and other aquatic life in polluted rivers have been found to contain significant residues of organochlorine pesticides (OCPs) and PCBs, raising concerns about food safety and chronic health effects such as cancer, endocrine disruption, and reproductive disorders (Rex and Chakraborty 2022). The state's rapid development has often outpaced the growth of adequate waste management and pollution control infrastructure, allowing POPs to persist in the environment (Government of Tamil Nadu, n.d.).

As international regulations and consumer awareness regarding POPs intensify, Tamil Nadu's industries, especially textiles, chemicals, leather, and electronics, face mounting pressure to align with global standards and ensure that their products are POPs-free (IPEN, 2022).

India, as a party to the Stockholm Convention, has banned the manufacture, import, and trade of most listed POPs, with only a few exemptions such as DDT for vector control (Department of Chemicals and Petrochemicals, Government of India, n.d.). Tamil

Nadu's industrial clusters, including those along the Cauvery River, often lack robust monitoring and inventory systems for POPs in raw materials, finished products, and waste streams. This gap increases the risk of unintentional POPs contamination in exports, which can lead to rejection of shipments, loss of market access, and reputational damage in key international markets, particularly the European Union, where POPs regulations are stringent (IPEN, 2022).

While India is a party to the Stockholm Convention and has developed a National Implementation Plan (NIP) to address POPs, translating these commitments into effective action at the state level remains difficult (India Environment Portal, 2011).

Capacity constraints further exacerbate these issues. There is a pressing need to strengthen the capabilities of state-level convention implementation bodies, including the establishment of dedicated POPs centres, advisory boards, and interdepartmental committees for chemical safety (India Environment Portal, 2011). Insufficient financial resources allocated for POPs management activities limit the ability to invest in best available technologies (BAT) and best environmental practices (BEP) for safe disposal, treatment, and control of POPs releases. Accountability is another persistent concern. The lack of transparent, standardised, and regular monitoring mechanisms makes it difficult to track the effectiveness of regulatory interventions and to hold polluters accountable for violations. Existing policies and regulations often require periodic review and updating to address emerging POPs and evolving industrial practices, but such revisions are slow and lack stakeholder engagement (India Environment Portal, 2011). Finally, sustained commitment to POPs management is challenged by competing policy priorities, limited public awareness, and the absence of long-term funding mechanisms.

4.2 Leveraging institutional and societal strengths

4.2.1 Science, research and innovation for POPs management

Tamil Nadu's strong base of universities, research institutions, and technical laboratories provides a great opportunity to generate a locally relevant scientific knowledge base on POPs. TNPCB has initiated compiling annual hazardous waste inventories; these efforts can be extended to include systematic data on POPs sources in the textile, leather, equipment manufacturing, oil and gas, and cement industries in the state.

By leveraging the existing network of monitoring stations for water quality managed by the TNPCB, the parameters related to POPs monitoring can be added. This network covers major river basins, including the Cauvery, and currently collects hydrological and in-situ data, as well as samples for basic water quality parameters, metals, and some pesticides. As per the Tamil Nadu State Environmental Policy (2017), the TNPCB will expand the Continuous Pollution and Emission Monitoring Systems across all industrial areas in a phased manner, covering all industrial areas managed by the State Industries Promotion Corporation of Tamil Nadu (SIPCOT), Tamil Nadu Industrial Development Corporation (TIDCO) Small Industries Development Corporation (SIDCO) and private developers. Hotspot assessment and prioritisation in the highly polluted Cauvery River basin, which is affected by numerous industries and sewer outlets, will enable state government agencies to focus their efforts on areas with the highest POPs contamination.

Monitoring protocols, manuals, and guidance documents specifically tailored for the analysis of POPs in various matrices (water, sediment, biota) in Tamil Nadu can be developed for state government laboratories and academic institutions. Furthermore,

a Tamil Nadu POPs Science Platform can be created to coordinate research efforts and provide robust evidence for policymaking. Its network of universities and research institutions (Anna University, IIT Madras, Tamil Nadu Agricultural University, and SRM Institute of Science and Technology) offers a great opportunity to conduct region-specific studies on POPs. Both legacy POPs such as PCBs, DDT, and HCH, as well as emerging POPs such as PFOS, PFOA, PBDEs, and SCCPs, can be monitored. Expanding research into POPs' prevalence in soil, water, food chains, and human health can inform targeted interventions.

Tamil Nadu's robust academic and industrial research ecosystem can accelerate the development of safer substitutes for POPs in pesticides, industrial chemicals, and consumer products. The government's support comes through an order (dated 23.08.2013) that calls for distribution of biocontrol agents/biopesticides and sale through agricultural extension centres (INOPOL, 2025)

Continued research and intervention are essential to address the human health risks posed by POPs. Collaborative research between public health institutions and environmental scientists can generate evidence on the long-term health impacts of POPs, for instance, on vulnerable groups such as women, children, and workers in informal e-waste recycling hubs around Chennai.

The Tamil Nadu Industrial Policy (2014) encourages technological innovation and has several provisions to minimise the release of POPs into the environment. Pilot projects at IIT Madras actively research diverse waste technologies, focusing on sustainable solutions for agricultural, municipal, and industrial waste. Such innovations can be extended to tackle POPs-contaminated materials.

4.2.2 Public awareness, initiatives, education and outreach

Consumer campaigns can empower people to make informed decisions about safer waste management

practices. Tamil Nadu has implemented consumer awareness campaigns that support efforts to ban single-use plastics and reduce plastic waste, including monthly cleanup drives and the promotion of reusable bags and eco-friendly alternatives, such as the *Meendum Manjappai* ('yellow cloth bag', encouraging people to reuse these as alternatives to plastics). Led by the TNPCB with support from government departments, volunteers, students, and local bodies, these campaigns have contributed to reducing plastic pollution and fostering increasingly sustainable practices (Government of Tamil Nadu, 2021).

Tamil Nadu has also established fishnet collection centres in major fishing harbours and coastal villages. Under the Tamil Nadu Fishnet Initiative (TNFI), a pilot implemented by M/s. Recity Networks at Kasimedu Harbour in Chennai, where fisherfolk are incentivised to collect discarded fishing nets for recycling. Fisherfolk are paid around ₹40 /kg for the collected fishnets, which are then transported to authorised recycling facilities for processing into plastic granules. With the support from the TNPCB, the TNFI is being expanded to additional locations, including Kovalam, Pazhaverkadu, Cuddalore, Pazhaiyar, Nagapattinam, Thoothukudi, and Kanniyakumari (Tamil Nadu Pollution Control Board, 2025).

To address the risks of severe damage and economic loss by pests and diseases, the USAID-funded project IPM-CRSP (Integrated Pest Management-Collaborative Research Support Program), with Tamil Nadu Agricultural University (TNAU) as a collaborator, has developed a bio-intensive IPM module that emphasises nonchemical components. Successful examples include the shallot IPM module in Perambalur, Dindigul, and Trichy districts, which emphasised nonchemical strategies and significantly reduced pesticide use. Building on these models, similar community awareness approaches could incorporate POPs-related awareness for farmers (Dinakaran et al., 2013).

Tamil Nadu's environmental education programs include the National Green Corps (NGC) programme, covering 500,000 students in 3,000+ schools, whereas the State Eco-Club Network supports 2,000+ school-based clubs to drive community initiatives. Complementing these, teacher training programs have equipped more than 10,000 educators with pedagogy tools, resource materials, and best practices related to environmental education (EEP-TN, 2025). This network can be used to educate youth on POPs pollution.

Popular media channels, including radio, television, newspapers, the internet, and social media, can serve as powerful tools for grassroots communication (Prathap & Ponnusamy, 2006). Using local languages, dialects, and folk media alongside digital platforms contributes to effective outreach to both rural and urban populations.

4.2.3 Stakeholder engagement and coordination

Establishing inclusive forums for regulators, farmers, industry, NGOs, and academia will enable dialogue, co-create solutions, and monitor the implementation of the POPs action plan in the state. The Tamil Nadu Climate Change Mission (under the State Department of Environment and Climate Change) convenes diverse stakeholders to shape strategies, generate evidence, and coordinate with line departments (Tamil Nadu Climate Change Mission, n.d.). Industrial associations can champion self-regulation and compliance and work with innovators to adopt cleaner technologies. Industries can play an active role in completing POPs inventories, including newly added industrial POPs. Industries should seek guidance from CSIR-NEERI for providing scientific and technical information on POPs. Tamil Nadu can leverage state-level platforms on waste management, chemical safety, and climate change to align POPs-related agendas with broader sustainability goals. The State Disaster Management Authority could integrate POPs considerations into chemical accident response protocols. Several large

companies (cement, chemicals, and textiles) in the state invest in Zero Liquid Discharge (ZLD) and waste minimisation practices.

4.2.4 Capacity building across sectors

State agencies such as pollution control boards, agriculture departments, and municipal authorities require enhanced technical and regulatory capacities in POPs identification, monitoring, and compliance. TNPCCB, in collaboration with the Central Pollution Control Board (CPCB), regularly conducts specialised training on environmental pollution issues, including hazardous waste management. With expanded curricula, these programs can train senior, mid-level, and field officers in internationally recognised yet locally adapted POPs detection protocols.

Beyond government agencies, capacity building should extend to farmer associations, industrial workers, waste pickers, and health workers, equipping them with practical knowledge to reduce POPs exposure risks and promote safer practices. Academic and training institutions can play a pivotal role: universities can integrate chemical safety and pollution management into curricula, while Industrial Training Institutes (ITIs) can introduce modules on hazardous waste handling and e-waste recycling to build a skilled workforce.

4.2.5 Leveraging financial and human resources

State budget allocations, including dedicated funding streams within environmental, health, and agriculture departments, can prioritise POPs management initiatives. The Tamil Nadu Green Climate Fund (2022) can allocate resources for POPs projects as part of broader environmental goals. Corporate social responsibility (CSR) investments can be channelled into POPs awareness, clean technology adoption, and community health interventions. Under pressure from international clients, the textile and leather industries are investing

in cleaner production technologies. These industries could co-finance POPs reduction projects.

Building on Tamil Nadu's skilled workforce, expertise can be directed toward research, monitoring, and clean technology deployment. Tamil Nadu's strong NGO workforce in waste management can be integrated into POPs-safe collection and disposal schemes. Also, Public-Private Partnership (PPP) models can be leveraged for hazardous waste treatment facilities, awareness programs, and innovation pilots (MoUD, CII & E&Y, n.d.).

4.2.6 Integration with global, regional, and national activities

At the global level, conventions such as Stockholm, Basel, Rotterdam, and Minamata provide technical and financial support while establishing accountability mechanisms; alignment with the Stockholm Convention, for instance, can enable access to technical assistance and pilot projects for safer disposal of obsolete pesticides. At the national level, integrating with India's National Implementation Plan (NIP) on POPs ensures consistency, avoids duplication, and allows the sharing of state-specific data and best practices while contributing to national targets. Regionally,

cooperation with and contribution to South Asian partner networks can strengthen monitoring, share knowledge and innovations, and harmonise responses to transboundary issues such as riverine and coastal pollution. Finally, POPs management contributes directly to the Sustainable Development Goals (SDGs), including health (SDG 3), clean water (SDG 6), sustainable cities (SDG 11), responsible consumption and production (SDG 12), and climate action (SDG 13).

Tamil Nadu, therefore, stands at a critical juncture in its efforts to reduce the long-term risks of POPs. Although the state continues to contend with polluted sites, fragmented regulatory systems, inconsistent compliance, and poor public knowledge, it also has important strengths that might transform its approach to chemical safety. Meaningful progress is made possible by the existence of strong research institutions, the likelihood of better interdepartmental cooperation, significant civil society involvement, and alignment with larger development missions. Tamil Nadu may advance toward a more robust and sustainable framework for managing POPs by investing in more robust monitoring systems, encouraging cleaner technologies, developing institutional capacity, and forming partnerships at the national and international levels.



Chapter 5

RECOMMENDATIONS, CONCLUSION AND WAY FORWARD

5.1 Recommendations

The preceding chapters examined the sources of POPs in Tamil Nadu, their pathways of environmental dispersion, regulatory frameworks governing their use and control, and the risks they pose to ecosystems and human health. These assessments reveal gaps in environmental monitoring, institutional coordination, and long-term chemical management. More importantly, they underscore the need to move beyond problem identification toward solutions that are practical, coordinated, and aligned with both national priorities and international obligations. The following chapter translates these scientific insights into a focused set of recommendations in a clear and actionable plan. The overarching approach is to adopt a phased, science-based, and participatory strategy to position Tamil Nadu as a national model for sustainable and safe chemicals management aligned with national and global frameworks.

Phased approach for POPs action plan

Phase I – Institutional Setup and Baseline Strengthening (0–6 months)

- Establish a State Hazardous Chemicals Steering Committee and thematic working groups.
- Conduct comprehensive baseline mapping of POPs sources, stockpiles, and contaminated sites.
- Strengthen laboratories and develop state-specific POPs monitoring and disposal SOPs aligned with the NIP.

Phase II – Capacity Building, Monitoring Network, and Regulatory Integration (6–18 months)

- Upgrade and accredit laboratories (within TNPCCB and partnering academic institutions) for POPs analysis, train regulators, industry, and technical agencies.
- Integrate POPs management into existing waste/environmental regulatory systems.
- Mandate industry-level phase-out and safe disposal plans as per POPs Rules, 2018.
- Launch a statewide Environmental Monitoring and Information System (EMIS) for real-time reporting and public access.
- Expand coordinated monitoring of air, water, soil, and biota across districts.

Phase III – Demonstration Projects & Stakeholder Engagement (18–36 months)

- Implement pilot projects (plastics, e-waste, textiles, healthcare waste) to demonstrate safer technologies and POP-free alternatives.
- Deepen partnerships with industry, academia, NGOs, and communities; roll out outreach and behaviour-change campaigns.

Phase IV – Full-Scale Implementation and Continuous Evaluation (36–60 months)

- Institutionalise POPs management across state systems and ensure compliance with national/Stockholm Convention commitments.
- Conduct periodic reviews; update the Action Plan to include new POPs, technologies, and policy developments.

Institutional strengthening: Roles and responsibilities

- Strengthen MoEF&CC leadership; enhance CPCB-SPCB coordination for monitoring and enforcement.

- Led by MoEF&CC, ensure that NIP for POPs is implemented by the key agencies (CPCB, CSIR-CPRI, CSIR-NEERI, CSIR-NIIST, as well as MoC&F, MoH&FW, and MoA&FW) through proper regulation, safer alternatives, sectoral POPs control, and public health risk management.
- Leverage CPCB, CSIR institutions (especially CSIR-NEERI serving as State/Central Resource Centre), and research bodies for POPs monitoring, risk assessment, development of inventories, and capacity building, including technical training for state agencies.
- Empower TNPCB/SPCBs for monitoring, compliance, and capacity development with health and research institutions.
- Involve NGOs/INGOs and INOPOL partner organisations for awareness, technical support, and knowledge dissemination.
- Maintain the functioning of institutional and regulatory frameworks to ensure transparency and effective POPs governance.
- Build capacities of staff on POPs management through trainings/workshops.
- Utilise 100% of allocated funds effectively and conduct periodic reviews of economic instruments.
- Ensure systematic POPs monitoring across human, environmental, and product samples through accredited laboratories with annual reporting.
- Ensure POPs stockpile identification, TSDF management, and safe disposal training to reduce risks from legacy POPs.
- Conduct ≥ 2 research collaborations with academia, provide lab support, and promote research on safer alternatives
- Ensure industries comply with POPs regulations through regulatory-industry knowledge exchange (industry notices, communication channels)

Resource allocation

- Upgrade technical skills, infrastructure, and lab capacity across governments, research centres, and academic institutions.
- Allocate dedicated funding for chemical pollution and POPs management beyond the “Control of Pollution” scheme.
- Leverage international financing and technical support (e.g., GEF, INOPOL) to augment state investments.
- Invest in human resources, research, and technology transfer to address emerging POPs and evolving monitoring needs.
- Utilise the benefits from the INOPOL project: developing institutional capacity, generating scientific knowledge, and strengthening policy development.
- Enhance awareness and capacity-building across policymakers, regulators, researchers, industry, and communities.

Key performance indicators

- Ensure $\geq 90\%$ annual monitoring of identified industries for POPs compliance, supported by regular interdepartmental coordination.
- Conduct ≥ 1 annual meeting with relevant departments to strengthen intergovernmental coordination.
- Conduct stakeholder consultations, awareness drives, and training with documented outcomes.

5.2 Conclusion

Drawing on the findings of the INOPOL Baseline Report, “Hazardous but Invisible: A Baseline Report on Persistent Organic Pollutants (POPs) in Tamil Nadu, India” (INOPOL, 2025), the POPs Action Plan for Tamil Nadu attempts to identify chemical contamination hotspots and engage relevant stakeholders in reducing the use and generation of both legacy and newly emerging contaminants, including plastic and POPs. The POPs Action Plan provides a comprehensive, science-informed framework for the safe and sustainable management of POPs, aligned with national priorities and India’s responsibilities under the Stockholm Convention. Its key objectives are to strengthen regulations and awareness among all stakeholders; assess gaps in environmental monitoring systems across relevant industrial sectors; promote research and knowledge generation on POPs, including their analyses, environmental fate, bioaccumulation, transport, and impacts on human health and ecosystems; identify challenges in adopting BEP and BAT and recommend practical solutions; provide science-informed recommendations to regulatory authorities for evidence-based decision-making;

identify funding opportunities beyond governmental sources; and build stakeholder capacities and awareness of long-term POPs impacts.

As the Government of India reviews and updates its National Implementation Plan, including control measures, action plans for unintentionally produced chemicals, and inventories of stockpiles, this Action Plan represents a state-level effort to align with national priorities while addressing Tamil Nadu's specific environmental and public health challenges. Effective coordination among key state departments such as the Department of Industries, Investment Promotions and Commerce (DIIPC), the Environment, Climate Change and Forests Department (ECCF), Agriculture - Farmers Welfare, Water Resources, and Health & Family Welfare, is imperative. Effective community awareness is also very crucial. The approaches outlined in this chapter can also be adapted for other states, supporting broader national efforts to minimise POPs risks.

Tamil Nadu finds itself at a crucial juncture in its efforts to manage POPs. As an industrially advanced and rapidly growing state, the environmental and public health risks associated with POPs demand a structured, science-driven, and coordinated response. The action plan demonstrates a clear pathway for Tamil Nadu to address legacy and emerging POPs through strengthened regulation, robust monitoring, capacity building, and stakeholder engagement. It also reaffirms the state's commitment to meeting its obligations under the Stockholm Convention and aligning with India's National Implementation Plan (NIP).

The phased strategy starts with institutional setup and baseline strengthening, followed by capacity building and regulatory integration, then sector-specific demonstration projects, and culminating in full-scale implementation and continuous evaluation. It creates a practical roadmap for measurable progress over five years. Implementing these phases will require coordinated action from the MoEF&CC, CPCB, TNPCB, sectoral ministries, state departments, research institutions, and civil society.

Strengthening laboratory networks, establishing monitoring systems across different environmental matrices (air, water, soil, sediments, and biota), and adopting best available technologies and practices are essential steps to build a comprehensive POPs management ecosystem in the state.

Institutional roles must remain clearly defined and actively coordinated. Central agencies, including the MoEF&CC, MoA&FW, MoH&FW, MoC&F, MoP, and CPCB, provide overarching policy and regulatory support, while state-level agencies such as TNPCB play a pivotal role in enforcement, monitoring, and on-ground implementation. Research institutions including CSIR-NEERI (as the Stockholm Convention Regional Centre), CSIR-CPRI, CSIR-NIST, and the INOPOL project partners: NIVA, Mu Gamma Consultants, SRMIST, Toxics Link are vital in advancing scientific understanding, developing inventories, building capacity, and supporting risk assessments. Civil society organizations complement these efforts by strengthening awareness, community engagement, and local outreach.

While progress is underway, resource constraints remain a challenge. Limited laboratory infrastructure, shortage of trained personnel, and the need for sustained financial investment must be addressed to ensure effective implementation. Leveraging Government of India budget allocations and international technical support, including the India-Norway INOPOL partnership, and strengthening domestic capacity will be crucial to overcoming these gaps. With new POPs continually added to the Stockholm Convention, Tamil Nadu must prioritize long-term investment in analytical capacity, toxicology expertise, and environmental risk assessment to keep pace with evolving challenges.

5.3 Way forward

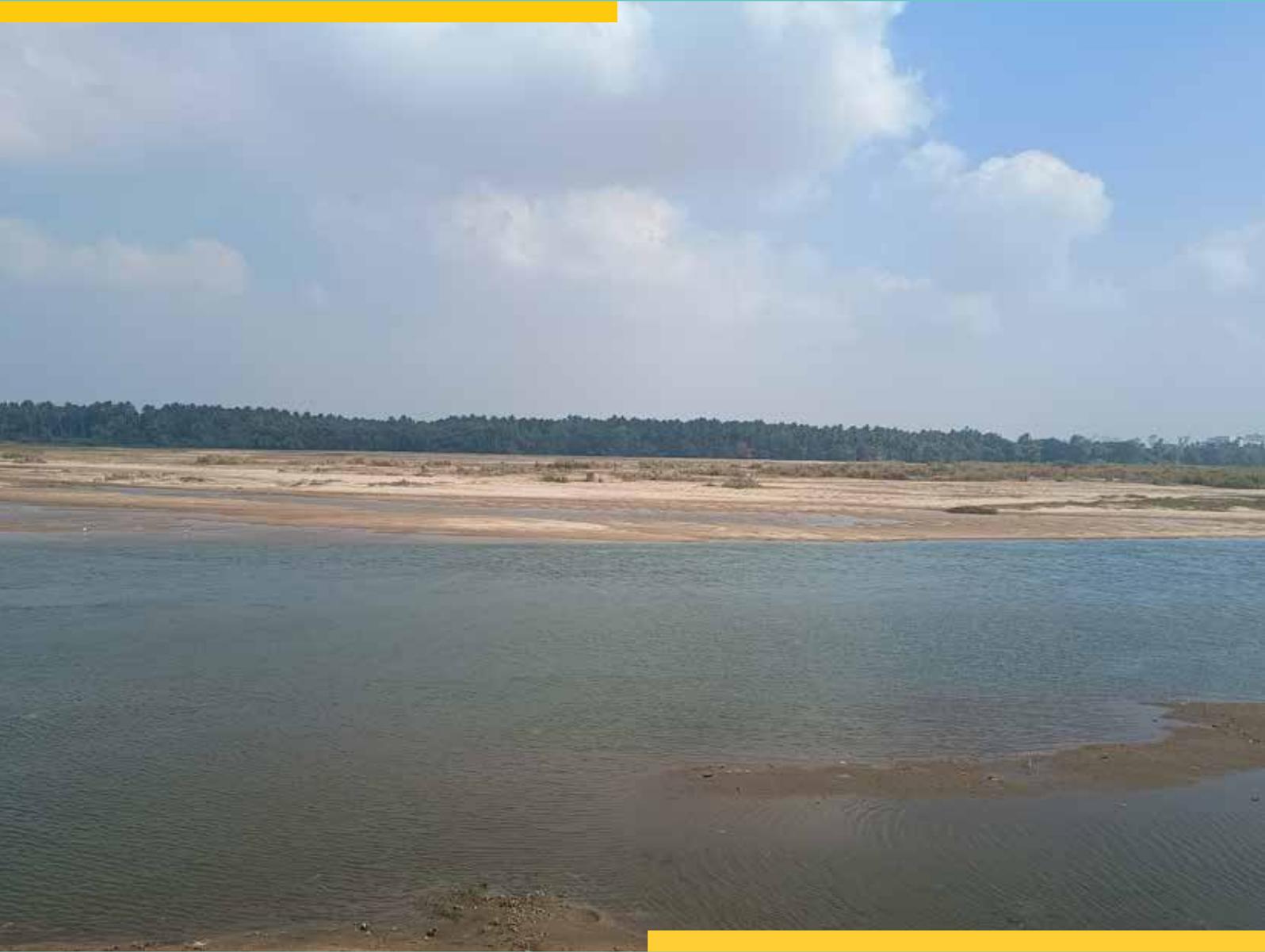
Tamil Nadu needs to emphasise research, innovation, and knowledge dissemination. Advanced studies on POPs exposure, public health impacts, and environmental effects will support evidence-based

policymaking. Additionally, behaviour-change campaigns and Information, Education, and Communication (IEC) initiatives will help reduce the public's risk of exposure and promote safe practices in various industries and communities. Below are some key highlights from the POPs Action Plan.

- Adopt a phased, science-based, and participatory strategy to establish Tamil Nadu as a national leader in sustainable and safe chemicals management.
- Establish institutional mechanisms, strengthen laboratories, and conduct baseline mapping of POPs sources, stockpiles, and contaminated sites.
- Build capacity, integrate POPs management into existing regulatory systems, and expand statewide monitoring through an EMIS platform.
- Implement pilot projects across key sectors and deepen partnerships with industry, academia, NGOs, and communities.
- Institutionalise POPs management, conduct periodic reviews, and update the Action Plan to include new POPs and evolving technologies.
- Strengthen roles of MoEF&CC, CPCB/SPCBs, CSIR institutions, and partner organisations for monitoring, enforcement, risk assessment, and capacity building.
- Allocate dedicated resources for labs, human resources, research, awareness, and leverage international support (GEF, INOPOL) for effective POPs management.

Therefore, Tamil Nadu's ability to protect environmental and human health from POPs pollution will lie in its commitment to collective action, bringing together regulators, industries, scientists, academia, civil society, and communities. This forward-looking approach will strengthen resilience, promote sustainable development, and ensure a healthier and safer future for the people of Tamil Nadu.





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Chapter 4

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NOTES

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**INDIA-NORWAY COOPERATION
PROJECT ON CAPACITY BUILDING
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(INOPOL)**

