Stockholm Convention

INOPOL

INDIA-NORWAY COOPERATION PROJECT ON
CAPACITY BUILDING FOR REDUCING PLASTIC AND
CHEMICAL POLLUTION IN INDIA (INOPOL)

HAZARDOUS BUT INVISIBLE

BASELINE REPORT ON
PERSISTENT ORGANIC POLLUTANTS (POPs) IN TAMIL NADU, INDIA

Norway | NIVA Norwegian Institute for Water Research | mu gamma | SRM | Toxics Link

Hazardous but Invisible: A Baseline Report on Persistent Organic Pollutants (POPs) in Tamil Nadu, India

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The baseline research was carried out under the scope of the India-Norway cooperation project on capacity building for reducing plastic and chemical pollution in India (INOPOL), under the Marine Pollution Initiative developed by the two governments and funded through the Norwegian Development Assistance Program to Combat Marine Litter and Microplastics. The INOPOL group would like to thank the project owner, the Royal Norwegian Embassy in New Delhi and the Norwegian Ministry of Foreign Affairs (MFA), for funding and supporting the project.

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Disclaimer

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Foreword

I am very pleased to launch this baseline report on the management of Persistent Organic Pollutants (POPs) in Tamil Nadu. I believe that this report will pave the way for meaningful action in addressing chemical pollution in the water sources.

Persistent Organic Pollutants (POPs) are toxic chemicals that persist in the environment, accumulate in the food chain, and pose significant risks to human health and ecosystems. Effective assessment and management of POPs are essential to mitigate these adverse impacts.

To address and prevent pollution from both land-based and offshore activities, Norway and India cooperate under the joint Marine Pollution Initiative. As part of the initiative, Norway supports a project on capacity building for reducing plastic and chemical pollution in India (INOPOL), implemented by the Norwegian Institute for Water Research (NIVA) and several Indian partners.

I congratulate the consortium of the Norwegian Institute for Water Research (NIVA), along with Indian partners such as; Mu Gamma Consultants Pvt. Ltd. (MGC), the Central Institute of Petrochemicals Engineering and Technology (CIPET), the SRM Institute of Science and Technology (SRMIST), and Toxics Link, on their cooperation and achievements in this important field.

May-Elin Stener

Ambassador, The Royal Norwegian Embassy in New Delhi

Foreword

Plastic pollution and persistent organic pollutants (POPs) pose a growing threat to ecosystems, human health, and livelihoods. Addressing these interlinked sustainability challenges requires diverse solutions at local and global levels.

To effectively reduce plastic and POPs pollution, we must identify where pollution originates and occurs throughout products lifecycle and how leaked contaminants impact people and environments. Science-based knowledge can contribute strengthening capacities to monitor, manage, and control plastic and POPs pollution and is especially crucial in countries where adequate pollution control systems, technologies and infrastructures are lacking.

At NIVA, we are fortunate to collaborate with leading Indian partners to bridge some of these knowledge needs as part of the India-Norway Cooperation Project on Capacity Building for Reducing Plastic and Chemical Pollution in India (INOPOL). INOPOL aims to provide science-based knowledge that drive solutions to reduce the harmful impacts of plastic and POPs pollution, by developing monitoring and data collection capacity, supporting policy implementation, identifying local challenges and provide science-based advice relevant government bodies.

POPs, a category of toxic chemicals known for their persistence in the environment and harmful health effects, require an integrated approach that spans regulation, research, capacity building, and public awareness. This report identifies gaps in POPs management and synthesises policies and research from national to international levels. With a specific focus on Tamil Nadu, the project facilitates informed decision-making and the development of a targeted strategy for reducing the harmful impacts of these pollutants.

The report emphasises the connection between POPs management and key sustainability targets and highlights how lessons from the Stockholm, Basel, and Rotterdam Conventions can be applied to the Indian context, contributing to a more integrated approach to chemical management and pollution control.

I hope this report will serve as a valuable resource for policymakers, researchers, and all stakeholders working towards a future free of plastic pollution. On behalf of NIVA, I extend my sincere thanks to Royal Norwegian Embassy in New Delhi and the entire project team for their dedicated efforts in preparing this report.

THORJØRN LARSSEN
Deputy Managing Director,
Norwegian Institute for Water Research (NIVA)

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List of ABBREVIATIONS AND ACRONYMS

ABS	Acrylonitrile-butadiene-styrene
ADME	Absorption, Distribution, Metabolism, and Excretion
ACAP	Arctic Contaminants Action Program
ACZA	Ammoniacal Copper Zinc Arsenate
ACQ	Ammonium Copper Quaternary
APCI-MS	Atmospheric pressure chemical ionization mass spectroscopy
APPI	Atmospheric pressure photo ionisation
ASAP	Asian Scientific Alliance for Plastic Pollution
ASE	Accelerated Solvent Extraction
ASSOCHAM	Associated Chambers of Commerce & Industry of India
BAT	Best Available Techniques
BBP	Benzyl Butyl Phthalate
BC	British Columbia, Canada
BCF	Bioconcentration Factor
BCM	Billion Cubic Meters
BDE	Bromodiphenly Ether
BEP	Best Environmental Practices
BHC	Benzene hexachloride
BIS	Bureau of Indian Standards
BFR	Brominated Flame Retardants
BMW	Biomedical Waste
BMWM	Biomedical Waste Management
BPA	Bisphenol A
BPCL	Bharat Petroleum Corporation Limited
BREF	Best Available Techniques Reference Document
BZT	Benzotriazoles
CALUX	Chemical-Activated Luciferase gene eXpression
CAGR	Compound Annual Growth Rate
CBMWTF	Common Bio-Medical Waste Treatment Facility
CCA	chromated copper arsenate
CETP	Common Effluent Treatment Plant
CIPET	Central Institute of Petrochemicals Engineering and Technology
CHLs	Chlordanes
CLD	Chlorine dioxide
CLS	chlorpyrifos
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CMR	Carcinogenic, Mutagenic Or Reprotoxic
CMSR	Chemical (Management and Safety) Rules
COP	Conference Of The Parties
COP-10	Conference of the Parties
CPCB	Central Pollution Control Board
CPRI	Central Power Research Institute
CSIR-IITR	CSIR- Indian Institute Of Toxicology Research
CSIR-NEERI	Council Of Scientific And Industrial Research National Environmental Engineering Research Institute
CSIR-NIIST	CSIR- National Institute For Interdisciplinary Science And Technology
CSO	Civil Society Organizations

CWC	Central Water Commission
DBP	Dibutyl Phthalate
DCM	Dichloromethane
DCOIT	4,5-dichloro-2-noctyl-4-isothiazolin-3-one
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DDX	Mixture of DDD, DDE etc
DecaBDE	Decabromodiphenyl ether
DEHP	Phthalates - Bis(2-Ethylhexyl) Phthalate
DEM	Digital Elevation Model
DIBP	Diisobutyl Phthalate
DL-PCB	Dioxin-like polychlorinated biphenyls
DNOC	Dinitro-Ortho-Cresol
DP	Dechlorane Plus
ECD	Electronic Circular Dichroism
ECHA	European Chemicals Agency
ECNI	Electron capture negative ionization
EDB	EDB (1,2-dibromoethane)
EDC	Endocrine Disrupting Chemical
EEA	European Environment Agency
EEE	Electrical And Electronic Equipment
EFSA	European Food Safety Authority
EI	Electron impact ionization
EI-MS	Electron impact ionization Mass Spectroscopy
EMPRI	Environmental Management and Policy Research Institute
EMS	Environmental Management System
EPA	Environmental Protection Agency
EPS	Expanded Polystyrene
ESDM	Electronic System Design and Manufacturing
ESFA	European Food Safety Authority
ESI	Electrospray Ionization
ESMWI	Environmentally Sound Management Of Medical Wastes In India
ESRI	Environmental Systems Research Institute
ETP	Effluent Treatment Plants
EU	European Union
EWR	Electronic waste recycling
FAO	Food and Agriculture Organisation
FDI	Foreign Direct Investment
FRC	fibre glass reinforced composite
FTUCA	Fluorotelomer unsaturated carboxylic acid
FY	Financial Year
GC-ECD	Gas Chromatography Electron Capture Detector (GC-ECD
GC-MSD	Gas Chromatography mass spectrometry detector
GC/MS/MS	Gas Chromatography Tandem Mass Spectrometry
GC-ECNI	Gas Chromatography Electron Capture Negative Ionization
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse gas
GoI	Government of India
GPI	Grossly Polluting Industries
GRULAC	Group of Latin America and Caribbean Countries
GSDP	Gross State Domestic Product
HBB	Hexabromobiphenyl
HBCD	Hexabromocyclododecane
HBCDD	Hexabromocyclododecane
HCB	Hexachlorobenzene
HCBD	Hexachlorobutadiene
HCH	Hexachlorohexane
HCH	Hexachlorocyclohexane
HCHs	Hexachlorocyclohexanes
HDPE	High-Density Polyethylene
HFR	Halogenated Flame Retardants
HIL	Hindustan Insecticides Limited
HIPS	High Impact Polystyrene
HRGC-HRMS	High-Resolution Gas Chromatography with High-Resolution Mass Spectrometer

HRMS/HRGC	High-Resolution Mass Spectrometer
HWTSDF	Hazardous Waste Treatment Storage And Disposal Facility
ICCM	International Conference on Chemicals Management
IFCS	Intergovernmental Forum on Chemical Safety
IISD	International Institute for Sustainable Development (IISD)
IKHAPP	International Knowledge Hub Against Plastic Pollution
INOPOL	India-Norway cooperation project on capacity building for reducing plastic and chemical pollution
INR	Indian Rupee
ISO	International Standards Organisation
IS	India Standards
IOCL	Indian Oil Corporation Limited
IPCP	International Panel on Chemical Pollution
IPEN	International Pollutants Elimination Network
IVPM	Integrated Vector Pest Management
KSPCB	Karnataka State Pollution Control Board
LC	Liquid Chromatography
LC-MS/MS	Liquid Chromatography Tandem Mass Spectrometry
LDPE	Low-Density Polyethylene
LLE	Liquid-liquid extraction
LLIN	Long-Lasting Insecticidal Nets
LOD	Limit of Detection
LOQ	Limit of Quantification
LRTAP POPS	Long-Range Transboundary Air Pollution On Persistent Organic Pollutants
LULC	Land Use and Land Cover
lw	Lipid weight
MAE	Microwave-assisted Extraction
MCCPs	Polychlorinated dibenzofurans
NCBI	National Center for Biotechnology Information
Kg/yr	Kilogram/year
MGC	Mu Gamma Consultants
MENA	Middle East and North Africa
MLD	Million Litres per Day
MMFM	Multimedia Faith Models
MNC	Multinational Corporation
MOE	Ministry of Environment
MOFAL	Ministry of Agriculture
MALR	Ministry of Agriculture and Land Reclamation
MERE	Ministry of Electricity and Renewable
MoEF&CC	Ministry of Environment Forest & Climate Change
MPs	Microplastics
MSD	Mass Spectrometry Detector
MRL	Maximum Residue Limits
MRM	Multiple Reaction Monitoring
MS	Mass Spectrometry
MSME	Micro, Small & Medium Enterprises
MSPD	Matrix Solid-Phase Dispersion
MT	Metric Tonne
N-EtFOSA	N-Ethylperflurooctane-1-sulfonamide
NCC	National Coordination Committee
NCI	Negative chemical ionization
NCR	National Capital Region
NCVBDC	National Center for Vector Borne Diseases Control
ND	Not Detected
NGO	Non-Governmental Organisation
NIAS	Non-Intentionally Added Substances
NIP	National Implementation Plan
NITI	National Institution for Transforming India
NIVA	Norwegian Institute for Water Research
NPs	Nanoplastics
NVBDCP	National Center for Vector Borne Diseases Control
NWA	National Water Awards

NWDA	National Water Development Agency
OBD	Open burning dumps
OC	Organochlorine
OCPs	Organochloro pesticides
Octa-BDE	Octabromodiphenyl ether
OECD	Organisation for Economic Co-operation and Development
PAH	Polycyclic Aromatic Hydrocarbons
PAS	Passive Air Samplers
PBB	Polybrominated Biphenyls
PBDD/F	Polybrominated Dibenzodioxins/ Furans
PBDE	Polybrominated Diphenyl Ethers
PBDEs	Polybrominated diphenyl ethers
PBT	Persistent, Bio-Accumulative, And Toxic
PC	Polycarbonate
PCB	Polychlorinated Biphenyls
PCB	Printed Circuit Boards
PCB	Polychlorinated Biphenyls
PCBs	Polychlorinated biphenyls
PCCP	Personal Care and Cosmetic Products
PCD	Department of Pollution Control Vietnam
PCDD	Polychlorinated Dibenzo-p-Dioxins
PCDD	Polychlorinated Dibenzodioxins
PCDF	Polychlorinated Dibenzofurans
PCDD/DFs	Polychlorinated Dibenzo-p-dioxins and Polychlorinated Dibenzofurans
PCDF	Polychlorinated Dibenzofurans
PCN	Polychlorinated Naphthalene
PCP	Pentachlorophenols
PCP	Phenylcyclohexyl piperidine
PCPIR	Petroleum, Chemicals And Petrochemicals Investment Regions
PCT	Polychlorinated Terphenyls
PeCB	Pentachlorobenzene
Penta BDE	Pentabromodiphenyl ether
PET	Polyethylene Terephthalate
PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances
PFAA	Perfluoroalkyl acids
PFCA	Perfluorocarboxylic Acids
PFHxS	Perfluorohexane Sulfonic Acid
PFHxS	Perfluorohexane sulfonate
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFOS-F	Perfluorooctanesulfonamidoethanol
PFOSF	Perfluorooctane sulfonyl fluoride
PFBA	Perfluorobutanoic acid,
PIC	Prior Informed Consent
PLE	Pressurized Liquid Extraction
POPRC	Persistent Organic Pollutants Review Committee
POPs	Persistent Organic Pollutants
PP	Polypropylene
PUF-PAS	Polyurethane foam Passive Air Samplers
PVC	Polyvinyl Chloride
PS	Polystyrene
RBI	Reserve Bank of India
REACH	Regulation For Registration, Evaluation, Authorisation And Restriction Of Chemicals
REACH SVHC	Substances Of Very High Concern
RoHS	Restriction on the use of certain Hazardous Substances
SAICM	Strategic Approach to International Chemicals Management
SAIL-BSP	Steel Authority of India-Bhilai Steel Plant
SAO	Senior Arctic Officials
SC	Stockholm Convention
SCCP	Short-chain Chlorinated Paraffins
SCCP	Short-Chained Chlorinated Paraffins
SCRC	Stockholm Convention Regional Centre
SDG	Sustainable Development Goals

SEA	Socio-Economic Analyses
SEZ	Special Economic Zone
SFE	Supercritical Fluid Extraction
SIAM	Society of Indian Automobile Manufacturers
SIDCO	Small Industries Development Corporation
SIM	Selected ion monitoring
SIPCOT	State Industries Promotion Corporation of Tamil Nadu
SOC	Soil organic carbon
SPCB	State Pollution Control Board
SPE	Solid-phase extraction
SPIC	Southern Petrochemical Industries Corporation Ltd
SPM	Suspended Particulate Matter
SPME	Solid-Phase Microextraction
SRMIST	SRM Institute of Science and Technology
SRTM	Shuttle Radar Topography Mission
STP	Sewage Treatment Plant
TEQ	Toxic Equivalency Quotient
TERI	The Energy And Resources Institute
Tetra-BDE	Tetra-polybrominated diphenyl ethers
TFA	Trifluoracetic acid
TIDCO	Tamil Nadu Industrial Development Corporation
TN	Tamil Nadu
TNPCB	Tamil Nadu Pollution Control Board
TNSIDCO	Tamil Nadu Small Industries Development Corporation
TOC	Total Organic Carbon
TOF	Time-of-flight
TPD	Tonnes per day

TSC	Technical Sub-Committee
TSCA	Toxics Substance Control Act
TWI	Tolerable weekly intake
UAE	Ultrasonic-Assisted Extraction
UNDCS	United Nations Development Cooperation Strategy
UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNIDO	United Nations Industrial Development Organization
u-POPs	Unintentionally Produced Pops
US	United States
USD	US Dollar
USEPA	United States Environmental Protection Agency
UV-328	UV-328 is a chemical compound that belongs to the family of hindered amine light stabilizers (HALS)
vPvB	Very Persistent and Very Bio-Accumulative
VEA	Vietnam Environment Administration
WEEE	Waste from Electrical and Electronic Equipment
WHO	World Health Organization
WRIS	Water Resources Information System
WQM	Water Quality Models
XPS	Extruded Polystyrene
ZLD	Zero Liquid Discharge

Executive SUMMARY

The India-Norway cooperation project on capacity building for reducing chemical and plastic pollution in India (INOPOL) is a collaborative initiative between the Norwegian Institute for Water Research (NIVA), Mu Gamma Consultants (MGC), the Central Institute of Petrochemicals Engineering and Technology (CIPET), the SRM Institute of Science and Technology (SRMIST) and Toxics Link. INOPOL aims to develop targeted, efficient, mitigative, and solution-oriented measures for the control and reduction of POPs and plastics pollution in Tamil Nadu and Uttarakhand in India through a multidisciplinary, cross-sectoral, and integrated approach.

This Baseline Report of Persistent Organic Pollutants (POPs) provides an overview of the pollution status, management aspects, as well as public health and socio-economic considerations of POPs pollution in the south Indian coastal state of Tamil Nadu, India. The report addresses the fate and transport of POPs pollution in natural environments, corresponding management efforts and limitations, and the health and socio-economic impacts stemming from the environmental and governance challenges of reducing POPs pollution. This baseline is a starting point for developing monitoring and data collection capacity, supporting the implementation of current policies, assessing local gaps and hurdles, identifying opportunities associated with implementation, and promoting science-based advice to local and national government bodies in the project region.

Tamil Nadu is a hub of several industrial clusters contributing to chemical and plastic pollution. Controlling pollution from key sources is the key to prevent environmental and health risks to surrounding ecosystems and communities. The Cauvery River connects people and communities in Tamil Nadu by providing essential water for drinking, agriculture, and industry, supporting local livelihoods, fostering cultural and religious practices, and linking various regions through its extensive basin and tributaries. However, it is considerably polluted by chemical and plastic waste, necessitating action to prevent further contamination. Developing baselines and assessing pollution hotspots and sources along the Cauvery River will help in building local capacities and identifying challenges and opportunities for reducing POPs pollution.

This Baseline Report on POPs introduces the key themes covered in each chapter, including the INOPOL project background, description of catchment areas, regulations, and policy status. It presents the status of POPs pollution in Tamil Nadu State, existing monitoring activities and methodologies, as well as health and environmental impacts of POPs (including the seven new POPs), international and Indian best practices of management of POPs, gaps and challenges, and the way forward.

Chapter 1 provides the project background, aim, scope of work, key project interventions, deliverables and expected outcomes. It emphasizes the project's objective to support the development and implementation of multiple regulatory frameworks for managing pollution in India through a multidisciplinary, cross-sectoral, and integrated approach. **Chapter 2** gives an overview of POPs and background of chemical industries, occurrence, distribution, and hot spots of POPs in Tamil Nadu. **Chapter 3** presents the description of pilot catchment areas (Cauvery River Basins), hydrological and physiographical context, mapping of the industrial units (chemical) along the river and status of legacy POPs and new POPs along the Cauvery river basin. **Chapter 4** dwells deeply into the regulatory framework, policies and programmes in POPs management in India and internationally. It also provides documentation of the global best regulatory practices, the National Implementation Plan (NIP) of India – review, updates, and implementation, regulatory framework and policy on chemicals and waste in Tamil Nadu. **Chapter 5** deliberates on the inter-linkages between POPs and plastics, the routes of exposure (micro, macro, plastic-borne chemicals), transport of POPs from the source to the sea, production of POPs from activities related to plastic waste management, role of the informal sector and unintended release of POPs and assessment of interface between informal, public, and private sector/industries. **Chapter 6** gives details of the environmental monitoring techniques of targeted POPs, which includes sampling techniques, extraction techniques for s samples (Water/Soil/Sediment/Biota), instrumental analysis of new POPs in various matrices using different techniques. **Chapter 7** presents environmental and health impacts and review of research studies on chemical and health impacts in Tamil Nadu. **Chapter 8** presents the international Best Available Techniques (BAT) & Best Environmental Practices (BEP) in the management of POPs. **Chapter 9** identifies research data gaps, knowledge and information gaps, policy and regulatory gaps, institutional and capacity gaps as well as technology gaps. **Chapter 10** gives recommendations and the way forward in managing POPs pollution in Tamil Nadu and more generally in India.

Chapter 1
INTRODUCTION AND PROJECT BACKGROUND

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1.1 Background

First Phase

The *India-Norway cooperation project on capacity building for reducing plastic and chemical pollution (INOPOL)* was set up to address the highly interlinked challenges regarding marine litter, microplastics and Persistent Organic Pollutants (POPs) in India. It focused on the two industrial regions of Surat and Vapi, in the State of Gujarat, and investigated the land sources, river fluxes and ocean input of plastic and POPs pollution, its socio-economic drivers and contributes with science-based support to ongoing initiatives. The Norwegian Institute for Water Research (NIVA) led the project in close collaboration with Indian partners, Mu Gamma Consultants (MGC), The Energy and Research Institute (TERI), Central Institute of Petrochemicals Engineering and Technology (CIPET), Toxics Link and SRM Institute of Science and Technology (SRMIST).

The first phase of the INOPOL project (2019-2022) focused on 'Developing Coherent Systems for Data Collection and Analysis' through developing river monitoring capacity on plastics and POPs pollution in specific project areas of Vapi and Surat in the western state of Gujarat in India. Further, it contributed with datasets on the handling of waste and identified the relevant industry sources of chemical and plastic pollution, thereby building a robust knowledge-based foundation for sound policymaking.

The INOPOL team has produced several scientific publications and is following the national and international processes related to plastic and POPs regulations closely, while engaging with key stakeholders to identify challenges and opportunities within the current policy environment, to optimize support towards ongoing implementation processes of plastic waste management rules and the Stockholm Convention on POPs.

The Key features of the INOPOL project's first phase are:

Time frame	January 2019- June 2022
Funding:	The Norwegian Ministry of Foreign Affairs
Program:	Development Assistance Programme Against Marine Litter and Microplastics/ India-Norway Marine Pollution Initiative
Project Management:	NIVA, in collaboration with TERI and MGC
Project partners:	NIVA, TERI, MGC, CIPET, SRM and Toxics Link
Case studies:	Surat, river Tapi (Tapti) Vapi, river Daman Ganga
Key outcomes:	Establish baselines on use and release Strengthen monitoring capacity and standardization Assess social drivers and impacts, and identify sustainable solutions Develop sound management tools

[1]Mu Gamma Consultants (MGC), [2]Norwegian Institute for Water Research (NIVA)

Second Phase

Building on the established and high-functioning partnerships in the *India-Norway cooperation project on capacity building for reducing plastic and chemical pollution in India (INOPOL),* the second phase of the project aims to support the reduction of plastic and Persistent Organic Pollutants (POPs) pollution in India with a focus and continued attention to contribute to solutions to manage POPs and plastic waste, and ultimately help protect the marine ecosystem from the toxicological impacts of plastics and POPs pollution.

Time frame	**September 2022- December 2025**
Funding:	The Norwegian Ministry of Foreign Affairs
Program:	Development Assistance Programme Against Marine Litter and Microplastics/ India-Norway Marine Pollution Initiative
Project Management:	NIVA, in collaboration with MGC
Project partners:	NIVA, MGC, CIPET, SRM and Toxics Link
Case studies:	Tamil Nadu, River Cauvery
Key outcomes:	Establish baselines on use and release Strengthen monitoring capacity and standardization Assess social drivers and impacts, and identify sustainable solutions Develop sound modelling and management tools

1.2 Project Summary of INOPOL's Second Phase

INOPOL project's second phase will take the work of the first phase further, applying a multidisciplinary, cross-sectorial and integrated approach to develop a coherent system for data collection in Tamil Nadu. **Tamil Nadu** is a major agricultural state of southern India with indiscriminate use of pesticides leading to observed environmental and health impacts due to chemical contamination. It is also an industrial state – its coastal cities house various heavy industries due to the prevalence of harbor activities causing chemical and plastic pollution. The project will aid the Tamil Nadu Government to implement the Stockholm Convention by eliminating or reducing environmental release of POPs through an assessment of point and non-point sources.

INOPOL project's second phase will scale up by establishing baselines in the selected states, develop monitoring and data collection capacity, support the implementation of current policies, assess local gaps and hurdles, as well as identify opportunities associated with implementation, and promote science-based advice to local and national government bodies. Study tours to Norway, online knowledge platforms and extensive dissemination schemes are being organised to accelerate exchange of scientific knowledge and understanding.

A strong focus in INOPOL project's second phase will be to enhance synergies and knowledge exchange between stakeholders in different Indian states – including, but not limited to Gujarat, Delhi, and Tamil Nadu – as well as between the states as well as at the national level. Through regular stakeholder platforms, the project will share scientific and policy relevant outputs – feeding into contemporary policy processes from time to time – including the international plastic treaty developments and negotiations. The findings of INOPOL project's second phase will also support the process of development of National Implementation Plan (NIP)-II and contribute to fulfilling India's commitment to meet its international obligations with regard to POPs management.

1.3 Aims and Objectives

The aim of the second phase of the project is to develop targeted, efficient, mitigative, and solution-oriented measures for control and reduction of plastic and POPs pollution in Tamil Nadu in India through a multidisciplinary, cross-sectorial, and integrated approach.

1.4 Scope of Work

The Outputs and the planned key activities of the Project are:

1. **Establish local monitoring capacity on POPs**
   - Data management and statistical analysis
   - Build local capacity for development of POPs monitoring plans
2. **Assessment of pollution sources (POPs + Plastics)**
   - Baseline assessment of plastic pollution sources
   - POPs inventorisation of industry and waste sources, including toolkit assessment
   - Hot-spot assessment and prioritization
   - Review of health and environmental impacts
3. **Regulation, management and impacts of POPs pollution**
   - Analysis of existing regulation and policy, including gaps / obstacles
   - Socio-legal study on regulation and policy enforcement and implementation
   - Social and economic impacts and benefits of prevention
4. **Education and dissemination**
   - Stakeholder workshops
   - Local-National integration activities
   - Government officials capacity strengthening
   - Sector-specific capacity strengthening
   - Annual seminars / workshops
   - Synergy exploration with other projects/activities

The expected impact of the project is to reduce POPs pollution in Tamil Nadu (TN) and the expected outcome is to achieve an improved performance in managing and reducing the use and impact of POPs in both states.

1.5 Project stakeholders

- Central Pollution Control Boards
- TN State Pollution Control Board
- UK State Pollution Control Board
- Urban Local Bodies of respective States
- Ministry of Environment, Forests and Climate Change
- Academic and research institutes in both TN and UK
- Industry associations
- NGOs and community groups and key research institutes.

1.6 Key project interventions, Key deliverables & Expected outcomes

Project INOPOL's second phase through its multidisciplinary project outcomes and corresponding outputs, support the development and implementation of multiple key policy and management frameworks (**Figure 1.1**). The project's key aim is to contribute to the generation of integrated, scientific data and knowledge that informs implementation and is guided by principles of sustainable and circular use of resources to protect the environment and human wellbeing from plastic and POPs pollution.

The theory of change of the second phase of INOPOL project is depicted in Figure 1.1.

The second phase of INOPOL project will also develop an online platform for sharing of experiences between different Indian states, with not just Tamil Nadu to be studied in the present project, but also other states and union territories. The platform will facilitate sharing of knowledge, experiences and best practices between government, scientists, and civil society actors. Further, to strengthen collaboration between Indian and Norwegian stakeholders, the project will organise study tours to Norway to exchange and share experiences, practices and scientific knowledge used to manage chemicals and plastic waste.

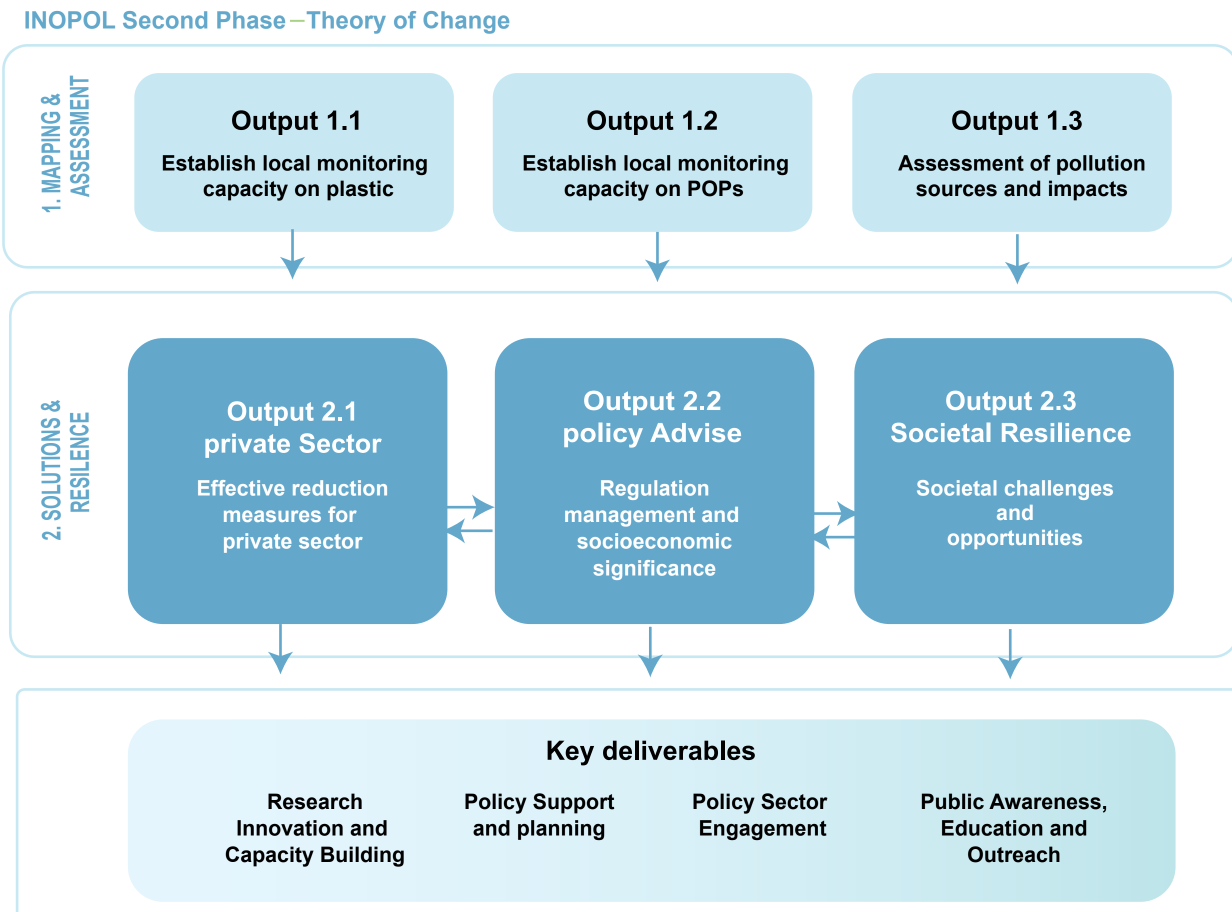

Figure 1.1: The outcomes, outputs, solutions, and resilience contributing to the four broad categories of deliverables of INOPOL project's second phase.

Chapter 2
BASELINE ASSESSMENT OF POPS POLLUTION IN TAMIL NADU

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2.1 Background of chemical industries in Tamil Nadu

The Indian chemical industry is both a knowledge- and capital-intensive sector. It holds great significance within the Indian economy and is experiencing continuous growth. With over 80,000 commercial items falling under various categories, the chemical sector plays a vital role in meeting essential needs and improving the quality of life in the country. It serves as a fundamental pillar for the industrial and agricultural development of the country and acts as the foundation for numerous downstream industries. India has been merging as the production house of the basic chemicals, and their by-products, such as petrochemicals, fertilisers, paints, varnishes, gases, soaps, perfumes, toiletries, and pharmaceuticals, are included in this industry.

According to reports, the Indian chemicals sector had a market size of approximately US $178 billion in 2019, and it is expected to expand to US $304 billion by 2025. Globally, India ranks 11th in the exports and 6th in the imports of chemicals (excluding pharmaceutical products). This industry represents 7% of India's GDP and constitutes around 14% of the overall index of industrial production (IBEF, 2024).

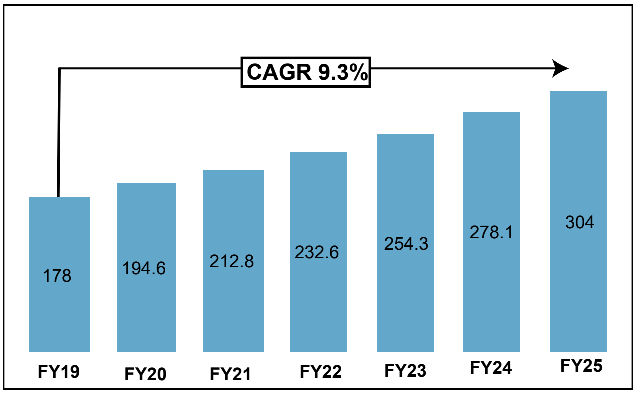

Figure 2.1: Indian chemical market size in US$ billion. *(IBEF, 2024).*

The production of major chemicals has witnessed a growth of 3.27% during the period of 2022-2023 Financial year (FY) in comparison to the same period of 2021-2022 FY with a major rise accounted for in pesticides and insecticides (10.51%), alkali chemicals (6.93%), and inorganic chemicals (1.56%). These growths in the chemical industries are contributed by different chemical clusters of the country.

Tamil Nadu is a state of India located in the southern part and is the fourth-largest state of the country. Its gross state domestic product (GSDP) is estimated to be Rs. 24.85 trillion (US$ 320.27 billion) in 2022-2023. It has established itself as a hub for automobile and auto components, textile, leather, cement, sugar, and engineering industries. The state has a robust presence in the production of organic and inorganic chemicals, industrial gases, and intermediates used in various industries.

Tamil Nadu is now the third largest contributor to the country's chemical output, as it is housing more than 2,500 chemical industries. Some of the prominent chemical industrial clusters in the state include Manali in Chennai, Ranipet, the SIPCOT Industrial Complex in Cuddalore, Tuticorin, and Madurai. These clusters provide a favourable environment for chemical companies to establish their operations, benefiting

[1]Toxics Link, [2]SRM Institute of Technology

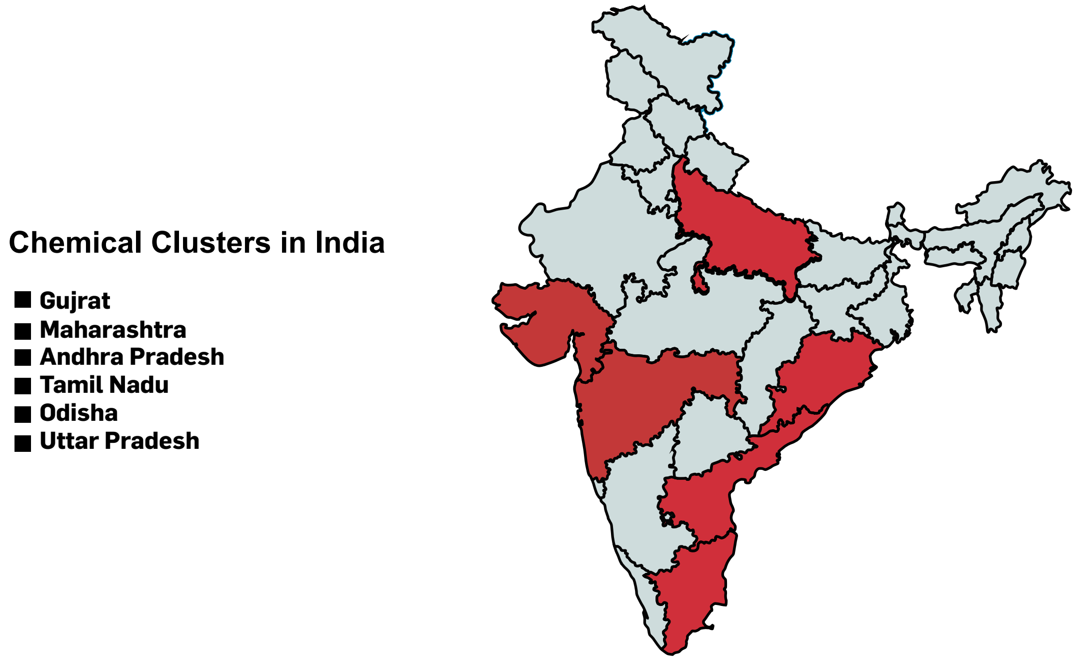

Figure 2.2: Chemical clusters of India

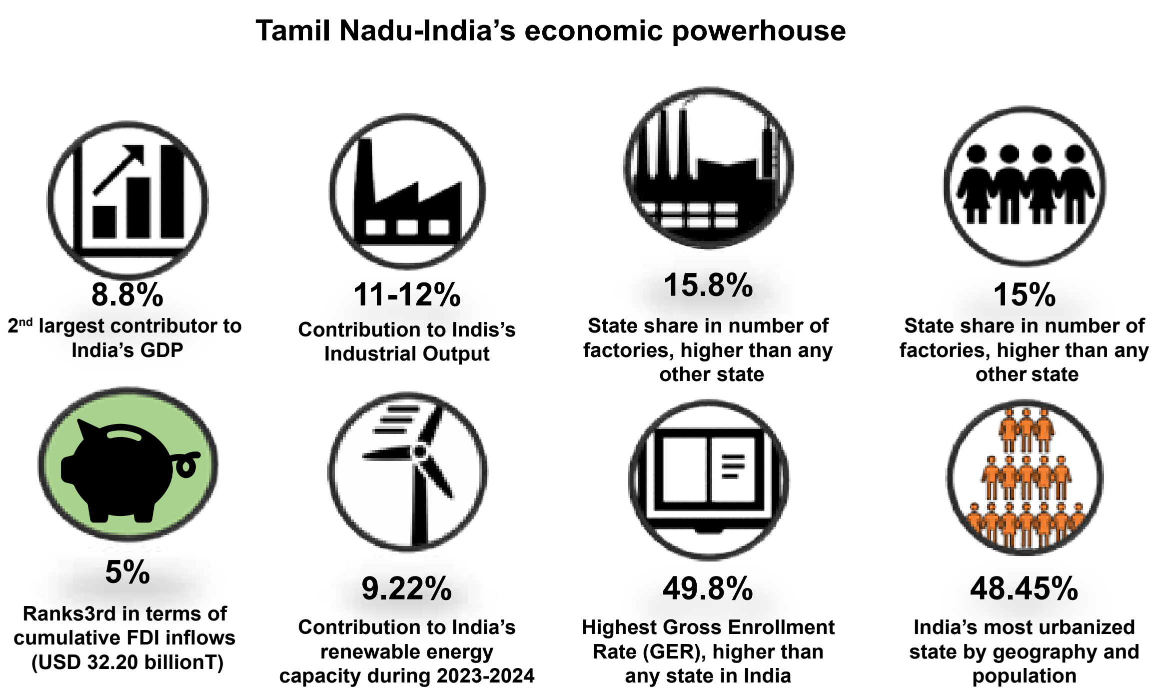

Figure 2.3: Economic Profile of Tamil Nadu.
(IBEF, 2024)

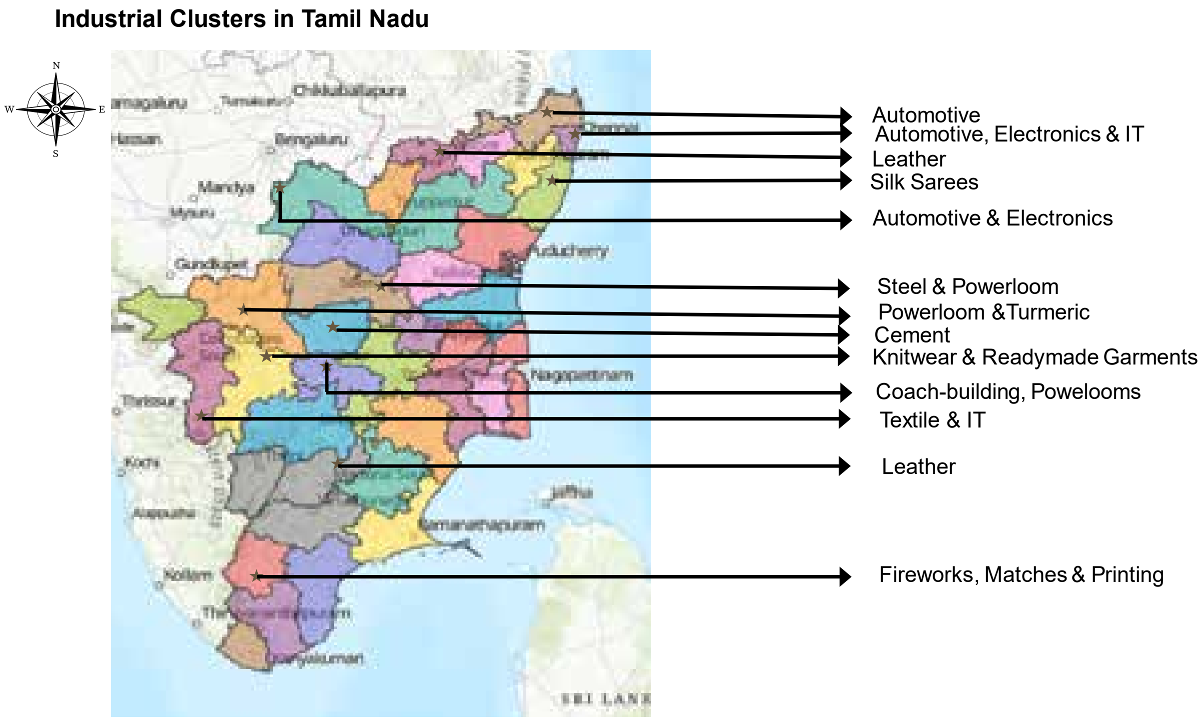

Figure 2.4: Industrial Clusters in Tamil Nadu

from infrastructure, connectivity, and proximity to raw materials and markets.

2.2 Occurrence and distribution of POPs in Tamil Nadu

2.2.1 Mapping of POPs related industry and waste sources

There is no comprehensive data on POPs usage and generation in the state. However, given the nature of the chemical industries in Tamil Nadu, it is very likely that POPs would be used in different processes and generated as waste as a result of their usage in the relevant sectors. Some industrial clusters where these POPs can be identified are highlighted below.

Chemical industry

Tamil Nadu has emerged as the major manufacturer and exporter of basic chemicals in the country. It is a leader amongst the South Indian states in terms of plastics production and consumption. Most of the chemical industries of Tamil Nadu are clustered around Chennai (Manali), Cuddalore, Panangudi (Nagapattinam), and Thuthukudi. The notable chemical industries have their bases in Tamil Nadu, such as Southern Petrochemical Industries Corporation Ltd. (SPIC), BPCL, IOCL, Manali Petrochemicals Ltd., etc.

Textile Industry

Tamil Nadu has a rich textile heritage and is known for its cotton spinning, weaving, dyeing, and garment manufacturing activities. The industry has a significant contribution to the state's economy and employment generation. Being the prominent centre for cotton spinning and silk, with a large number of mills located, Coimbatore is known as the "Manchester of South India," while Karur city is known as the 'Textile Capital of Tamil Nadu' and Tiruppur is known as the "Dollar City." Arani,

Figure 2.5: Textile industries in Tirupur, Tamil Nadu

Rasipuram, and Thirubuvanam are also silk centres of Tamil Nadu. Bhavani and Kumrapalayam are the major centres of carpet production. The state government has established textile parks and industrial estates, such as the TIDEL Park in Coimbatore and SIPCOT Industrial Estate in Tirupur, to provide infrastructure and support to the textile industry.

There are many chemicals that are designated as POPs are linked to textile industries. Halogenated flame retardants (specially brominated flame retardants (BFRs)) such as Octa-BDE, Penta-BDE, hexachlorobutadiene, hexabromocyclododecane, etc. and chlorinated paraffins such as short-chain chlorinated paraffins (SCCPs) are widely used in fabrics to enhance their flame resistance, such as in products like upholstery, curtains, carpets, mattresses, children's sleepwear, protective clothing, and industrial textiles.

In the textile industry, PFAS congeners are commonly used for their water-repellent and stain-resistant properties. They are applied to fabrics as a coating or finish to enhance their performance and durability. For example, outdoor clothing, raincoats, upholstery, and carpets may be treated with PFAS to make them resistant to water, oil, and dirt.

Polychlorinated biphenyls were once used in the textile industry for various purposes, including as a heat transfer medium in dyeing and printing processes. (State of Oregon, 2003). Since its ban, Polychlorinated biphenyls are no longer used in the industry; however, considering their persistent nature, there is the possibility of their presence in nearby premises.

Similarly, UV-328, which has been designated as a POP at the 11th Conference of the Parties (COP) is used for garments that are designed for outdoor activities or water sports, where prolonged exposure to the sun is common. It can also be used in curtains, upholstery fabrics, and other home textiles to prevent fading and deterioration caused

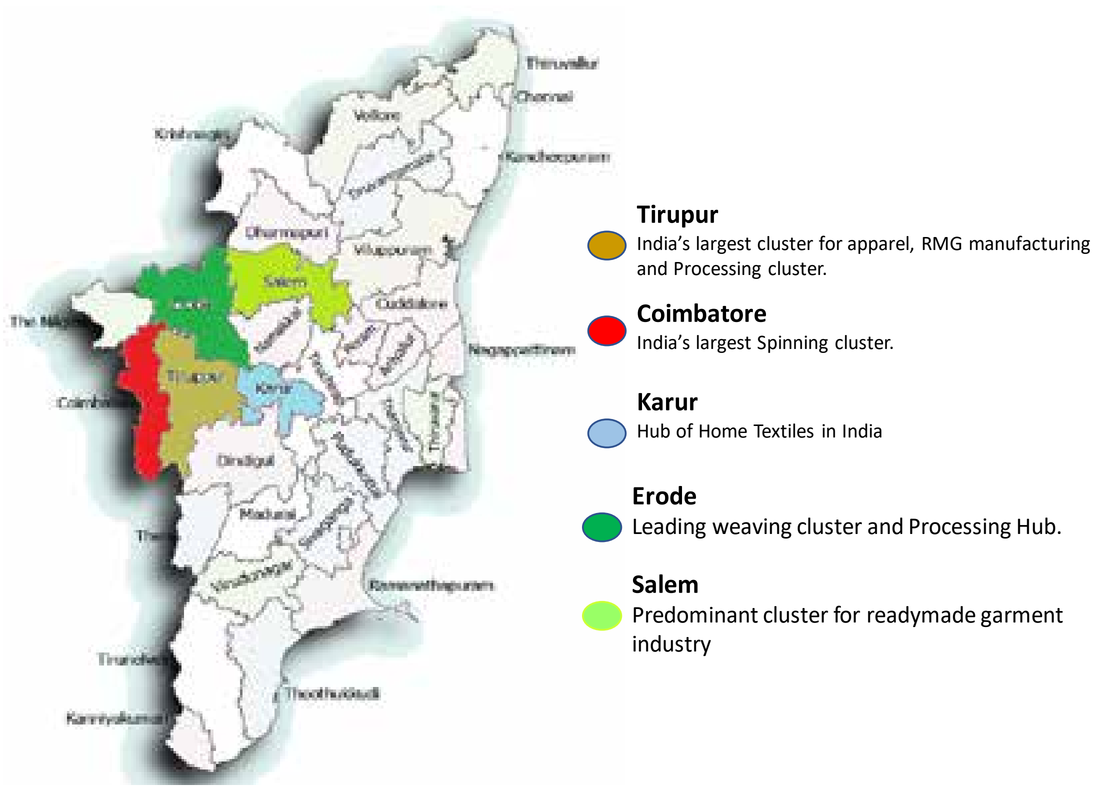

Figure 2.6: Major centres of textile arena in Tamil Nadu.
(Department of Textile, Go TN, 2023)

by UV radiation entering through windows and other sources of sunlight.

Automobile Industry

Tamil Nadu stands as one of the world's top ten automobile hubs, deriving 8% of its GDP from the automobile industry. Additionally, it holds the distinction of being the largest state for tire manufacturing within the country. Chennai city serves as the base for 30% of India's automobile production and 35% of its auto components; due to its industrial supremacy, it is often referred to as the 'Automobile Capital of India' and 'Detroit of Asia'. As one of the leading manufacturing hubs in the world, it has more than 1300+ factories linked to this sector. Chennai boasts an annual installed capacity of 1.71 million units for vehicle production. Besides national firms, several MNC firms like Hyundai, Ford, Renault-Nissan, etc. also have their manufacturing units in the state. Hosur and Coimbatore have also developed as auto clusters with manufacturing facilities for rail transportation products. Namakkal, Tiruchengode and Karur are known for their truck body building industries (Government of Tamil Nadu, 2024). 100% FDI allowed under automatic route without prior approval required from GoI or RBI which eventually help to boost the automobile industry in Tamil Nadu.

There are POPs associated with the automobile industries. Halogenated flame retardants (HFRs) have been used in the automobile industry to improve fire safety and meet certain regulatory requirements. They are often used in wiring harnesses, connectors, engine components, and under-the-hood applications to enhance fire resistance in vehicles. HFRs are used in various interior materials such as seat covers, carpets, and foam cushions. With the increasing use of electric

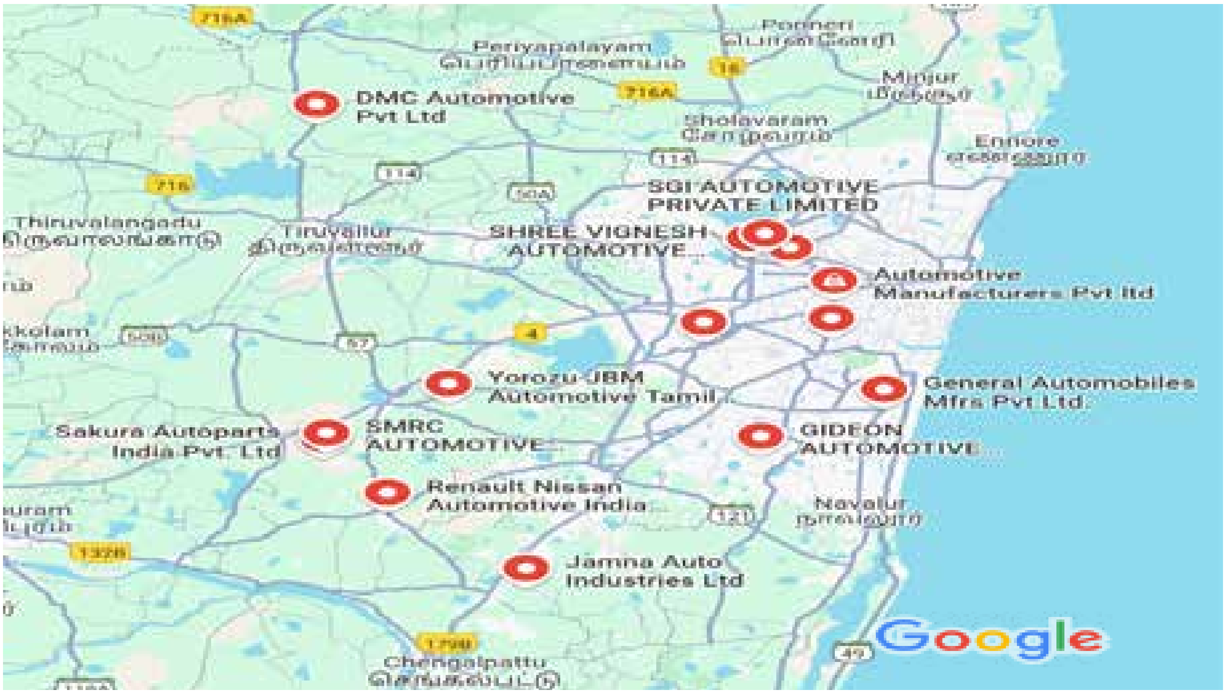

Figure 2.7: Automobile industries in Chennai, Tamil Nadu

and hybrid vehicles, flame retardants are utilised in battery systems to reduce the risk of thermal runaway and fire hazards. They can also help to improve the safety of battery packs and prevent the propagation of fires in the event of a battery failure.

PFAS coatings are used on automotive carpets and floor mats, seats, carpets, and headliners to make them resistant to stains, spills, and dirt. PFAS are used in weatherproof coatings for automotive components such as exterior panels, trims, and moldings. PFAS compounds have been used in wire and cable insulation within automobiles due to their excellent electrical properties, such as high dielectric strength and low electrical conductivity. Certain PFAS compounds have been used in brake and clutch fluids for their ability to withstand high temperatures and provide effective lubrication and hydraulic performance.

Chlorinated paraffins are used as plasticizers for polyvinyl chloride, as extreme-pressure additives in metal-machining fluids, and as additives to paints, coatings, and sealants.

In the automobile sector, UV-328 is used in automotive paints, coatings, and sealants, as well as in liquid crystal panels and meters mounted on vehicles, and resin for interior and exterior parts of vehicles (UNEP, 2023).

Electronic (hardware) Industry

With a focus on promoting Electronic System Design and Manufacturing (ESDM), Tamil Nadu has become a key state for electronics hardware production and exports within the country. It holds a substantial share, accounting for 20% of the total electronics production in India, and ranks second in the country for computer, electronics, and optical products manufacturing. Tamil Nadu is home to over 15 leading electronics manufacturers. Chennai has emerged as the Electronics Manufacturing and Services (EMS) hub of India. Two Special Economic Zones (SEZs) for the Electronic Hardware Sector are established in Kancheepuram District. Several companies like Sony Ericsson, Samsung, Cisco, Dell, etc. have chosen Chennai as their South Asian manufacturing hub.

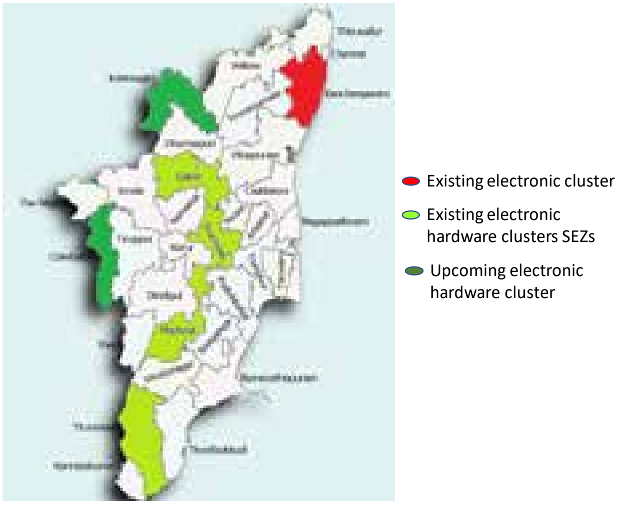

Figure 2.8: Electronics cluster in Tamil Nadu. (India Briefing Ltd, 2023)

BFRs are also used in electrical and electronic applications such as cables, connectors, machineries, and other components to meet fire safety regulations and reduce the risk of fire propagation.

PFAS compounds have been used as insulation materials for wires and cables due to their excellent electrical properties, such as high dielectric strength, low electrical conductivity, and resistance to heat and chemicals. They help ensure reliable electrical connections and protect against electrical failures. PFAS are used in the manufacturing of printed circuit boards which are essential components in electronic devices. They are used as solder masks and surface finishes to protect and insulate the copper traces on the printed circuit boards. They have been used in the encapsulation of electronic components and as dielectric materials in capacitors.

Polychlorinated naphthalene is used for insulating electrical wires and others. It is mainly used in the electrical industry as separators in storage batteries, capacitor impregnates, as binders for electrical grade ceramics and sintered metals, and in cable covering compositions.

Polychlorinated biphenyls (PCBs) were also commonly used for the capacitor's voltage regulators, switches, re-closers, bushings, and electromagnets. Further oil that is used in motors and hydraulic systems and old electrical devices or appliances containing polychlorinated biphenyls capacitors.

Pesticides Industry

Many pesticide and fertiliser companies are based in Cuddalore, Coimbatore, Salem, Madurai, Chennai, etc. The consumption of chemical pesticides in FY 2021-2022 in Tamil Nadu was reported to be 1851 MT, while the demand was 2064 MT (Directorate of Plant Protection, Quarantine and Storage, 2023a;

JAYFOL - Product Information

JAYFOL is an organochlorine acaricide/miticide structurally similar to DDT. It is highly effective in controlling **red spider mites** on crops like tea, vegetables, and fruits.

Product Details

Attribute	Description
Active Ingredient	Dicofol
Formulation	18.5% EC (Emulsifiable Concentrate)
Mode of Action	Contact miticide; acts on the central nervous system of mites.
Compatibility	Compatible with most insecticides, fungicides, etc.
Shelf-life	Two years under normal storage conditions.
Available Packing	100 ml, 250 ml, 500 ml, and 1 Liter.

Key Features

•**Highly effective** against red spider mites.
•**Widely used** in tea, vegetables, and fruit crops.
•**Fast-acting** mode of action via direct contact.

Figure 2.9: Commercial organochlorine pesticide (Sabari Crop Care, 2024)

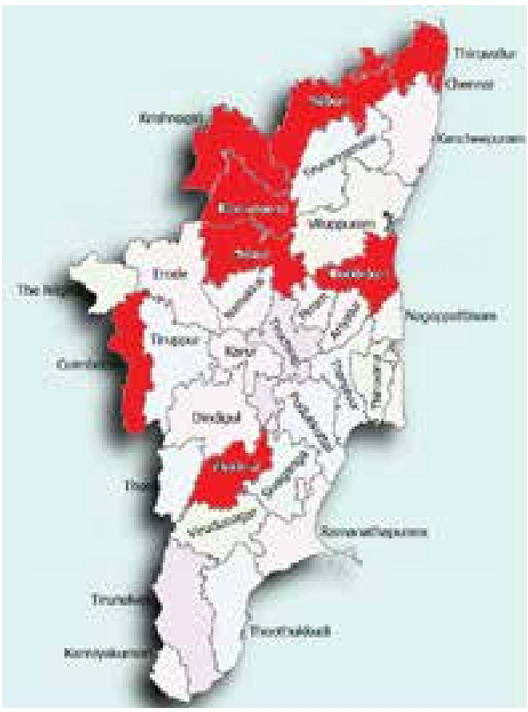

Figure 2.10: Pesticide manufacturing cluster in Tamil Nadu

Directorate of Plant Protection, Quarantine and Storage, 2023b). Although organochlorine pesticides enlisted as POPs in the Stockholm Convention are banned in India, many are still in use. Organochlorine pesticide (OCP) such as dicofol, beta-HCH, alpha-HCH, etc. are still not banned in the country. Several research studies have reported these banned pesticides in different environmental matrices.

E-waste Recycling

Tamil Nadu is the second largest e-waste generator in India. According to ASSOCHAM and State Pollution Control Board estimates, the state produces approximately 13% of the total e-waste in India, which accounts for nearly 400,482 MT/annum of waste. The districts of Chennai, Maduarai, Trichirapalli, and Vellore are critical hotspots of e-waste production in Tamil Nadu, as they produce 52%. For reference, the Chennai metro region (combined with figures of revenue districts surrounding the state capital region) produced 81,229 MT e-waste in 2020. This estimate would reach 133,887 MT by the year 2030 (National Productivity Council, 2021). The treatment of waste differs from collection centres and their different municipalities. Tamil Nadu has 193 collection sites and 24 recyclers in the whole state, the majority of which are present in Chennai (31%).

Electronic appliances that are composed of various kinds of components like printed circuit boards(PCBs), thermocol and packaging material, plastic, etc. Each component within it is a potential source of POPs. For e.g., in plastic and printed circuit boards,additives such as polybrominated flame retardants diphenyl ethers (PBDEs), and Per and polyfluorinated alkyl substance (PFAS) are added (Chakraborty et al., 2022; Xiu et al., 2019). Hence, improper disposal of these materials would result in the subsequent release of POPs into the environmental matrix. A study carried out by SRM and collaborators in 2017 found high levels of Polychlorinated Bisphenols in soil, with the highest concentration being in an informal e-waste shredding site (Chakraborty et al., 2017)

With the increase in e-waste yearly (production and imports), without the implementation of regulations and restrictions, more POPs are expected to be released into the environment.

Effluent treatment plants in Tamil Nadu

In Tamil Nadu there are 37 CETPs in the state of which 13 are in the tannery sector, 22 have been installed for textile bleaching and dyeing units while two CETPs are pertaining to the Cluster Electroplating Industries. In 2021, the state government has announced to establish 10 CETPs in Erode & Namakkal districts to control pollution from textile & dye industries.

Three online continuous water quality monitor systems are installed in the Cauvery, Noyyal, Bhavani, and Kalingarayan rivers to monitor water quality on a real-time basis. The facility also covers Thamirabarani in Tirunelveli district.

Figure 2.11: An effluent treatment plant in Tamil Nadu. (Water Care Equipments & Services, 2024)

However, many discrepancies have been observed in these CETPs. In 2019, TNPCB reported that twenty CETPs were running without a license (CPCB, 2019). There are annual closures of CETPs in the tannery and textile and dyeing sectors due to a lack of adherence to the ZLD norm. 10 CETPs (8 CETPs in Karur and 2 CETPs in Tiruppur) were under closure in view of the orders of the Hon'ble High Court due to their inability to achieve ZLD standards (TNPCB 2021).

Plastic Waste in Tamil Nadu

Tamil Nadu has Rs 15,000 crore plastics industry that comprises of 8,000 factories. TNPCB states that approximately 1178 tonnes of plastic waste are produced daily by 15 corporations, 121 municipalities, and 528 Town Panchayats in Tamil Nadu. Out of this amount, the urban bodies collect and separate 96%, selling the recyclable plastic waste to recyclers and sending the non-recyclable plastic waste for co-incineration in cement plants. (TNPCB, 2021) However, in its annual report, it has also reported that only 689.75 (TPD) had been processed. This shows the lack of information on the remaining plastic waste.

HFRs, chlorinated paraffins, PFAS, UV328, dechlorane plus are commonly used POPs in the plastics industry as additives, surfactants, flame retardants, etc. Improper disposal of plastic waste may cause leaching of these POPs in environmental matrices.

TNPCB also reported that in 2019-2020 Financial Year (FY), approximately 655 tonnes of non-sealable and non-recyclable plastic waste were used for laying 536 km of road. This also leads to the leaching of POPs from such plastic wastes.

Research studies have reported the release of dioxins, furans, and polychlorinated biphenyls PCB-like dioxins from improper burning of plastic waste materials.

2.2.2 POPs hotspot assessment and prioritization

The River Cauvery, known also as Ponni, holds immense importance as a major watercourse within the state, draining over one-third of its territory. Its origins can be traced to the foothills of the Western Ghats at Tala Cauvery, located in Kodagu, Karnataka. Flowing predominantly in a south and eastward direction, it traverses the states of Karnataka and Tamil Nadu, winding its way across the southern Deccan plateau and the southeastern lowlands before ultimately merging with the Bay of Bengal through two primary outlets in Poompuhar, Tamil Nadu. The Cauvery Delta, renowned for its remarkable fertility, owes its existence to the river's valleys, establishing it as one of the most agriculturally productive regions in the country. The livelihoods and sustenance of millions of people are heavily reliant on the Cauvery River, underscoring its pivotal role in the region.

Regrettably, the Cauvery River faces a dire threat from POPs. These harmful chemicals accumulate in the environment, posing significant health hazards to humans, wildlife, and ecosystems. The extent of pollution resulting from diverse domestic and industrial activities positions the Cauvery River as a crucial case study for understanding the repercussions of such contaminants. Numerous industries situated along the riverbanks are the primary contributors to the presence of POPs in the water (Devarajan et al., 2015; Ranganathan

& Bratman, 2021). They discharge hazardous substances such as pesticides, herbicides, and industrial solvents directly into the river, exacerbating the pollution. The improper disposal of industrial waste, particularly from textile, chemical, and electronics manufacturing units, substantially compounds the issue (Mageshkumar et al., 2022).

There are approximately 2,638 industries situated in the districts along the course of the Cauvery River. Among these, tanneries, dyeing, and bleaching industries located in the polluted sections discharge an estimated 49,724 million litres per day (MLD) of effluents (as per TNPCB 2023 data). Additionally, the areas surrounding the river contend with 75 sewer outlets, producing approximately 142.9 MLD of wastewater daily. Furthermore, there are seven solid waste disposal sites near the river, resulting in the daily generation of 888.12 tonnes of solid waste and seven open dumping points (TNPCB, 2023).

Recognising the vital role of the Cauvery River in the lives of millions and its ecological significance, it is imperative to urgently address the issue of POPs and pollution. A comprehensive and coordinated effort is essential to regulate industrial practices, promote responsible waste disposal, and implement effective water treatment measures. These actions are crucial for safeguarding the health of the river and ensuring the well-being of the communities it sustains.
The Cauvery River holds the distinction of being categorised as a class I priority by the Tamil Nadu

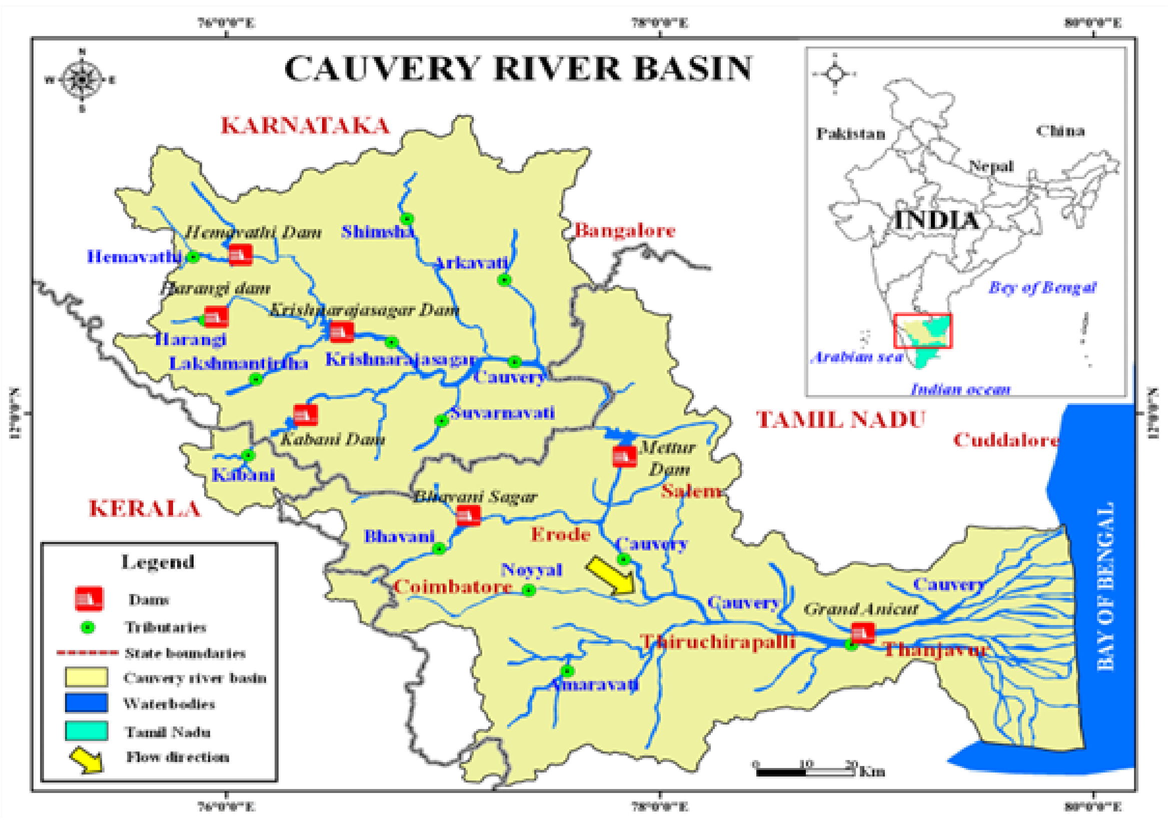

Figure 2.12: Map of Cauvery River Basin

1. Mettur
2. Pallipalayam
3. Musiri Borewell
4. Musiri Ferry Gate
5. Komarapalayam
6. Urachikottai
7. Seerampalayam
8. Pugalur
9. Pettavaithalai
10. Kumbakonam
11. Mayiladurai
12. R.N. Pudur
13. Vairapalayam
14. P. Velur
15. Mohanur
16. Thirumukkudal
17. Trichy Upstream
18. Trichy Downstream
19. Grand Anicut

Pollution Control Board, and the TNPCB has identified 19 polluted river stretches along the Cauvery River, as listed below.

2.3 Use, emission, and release of POPs into the environment

2.3.1 Status of legacy and new POPs in the state

A research study conducted in the eggs of 22 terrestrial bird species from Tamil Nadu, India, investigated the levels and distribution pattern of organochlorine pesticide residues (Venugopal et al., 2020). The study focused on analysing organochlorine pesticide (OCP) residues present in eggs abandoned by these bird species during nest monitoring between 2001 and 2008. The results revealed varying concentrations of different pesticide residues. The mean concentrations of total hexachlorohexane (ΣHCHs), total dichlorodiphenyltrichloroethane (ΣDDTs), heptachlor epoxide, and dieldrin ranged from non-detectable (nd) to 2800 ng/g, nd to 1000 ng/g, nd to 700 ng/g, and nd to 240 ng/g, respectively, based on a wet mass (wm) basis. Organochlorine residues (HCHs, DDTs, and PCBs) in various bird species from different trophic groups in Tamil Nadu, India, showed no significant variation based on the sex of the birds (Sethuraman & Subramanian, 2003).

However, females generally had lower residue levels compared to males, considering their mean weight and feeding habits. Levels of OCP residues in nine species of freshwater fish from three bird sanctuaries in Tamil Nadu, India, were studied in a total of 302 fish samples (Samidurai et al., 2019). HCH was the most frequently detected pesticide, with β HCH being the dominant isomer. The metabolite of DDT, *p,p'* DDT, was also present in high percentages. Endosulfan, a cyclodiene insecticide, was detected in over 60% of the fish samples. While varying levels of ΣOCPs were found in different fish species, no significant differences were observed ($p > 0.05$). However, there were significant variations in OCPs between locations and seasons ($p < 0.05$). (Dhananjayan et al., 2011) assessed the contamination of organochlorine pesticides (OCPs) in eggs and tissues of House Sparrow (*Passer domesticus*) in Tamil Nadu, India. The study found that the mean concentrations of total HCH and total DDT in eggs ranged from 0.01 to 1.81 μg/g and 0.02 to 1.29 μg/g, respectively. The concentration of *p,p'*-DDE ranged from below detectable limits to 0.64 μg/g, constituting more than 60% of the *p,p'*-DDT. Approximately 28% of the samples had *p,p'*-DDE levels above the critical concentration associated with reproductive impairment. However, the mean concentrations of cyclodiene insecticides were below 0.5 μg/g. OCP residues in colonial nesting birds in Tamil Nadu, India, were analysed in 76 individuals from 14 bird species that were found dead between March 2008 and March 2010 (Jayakumar et al., 2020). Among all the OCPs, the highest concentration was found for HCH. The contamination levels varied significantly among different bird species. The accumulation pattern of OCPs in colonial nesting birds was ΣHCH > Σendosulfan > ΣDDT > heptachlor epoxide > dieldrin. The pesticides p,p-DDE and β-HCH were the major contributors to the total OCPs detected in the birds' tissues.

In 1991, levels of the insecticide HCH (hexachlorocyclohexane) in the Vellar estuary in Tamil Nadu, South India, were surveyed along with the estuary's physical structure and hydrokinetic parameters to understand contaminant transport in tropical coastal areas (Takeoka et al., 1991). The results indicated that most of the HCH applied to the catchment area of the Vellar River is removed through the air, with only a small portion draining into the sea. In the past, when the river structure was different from the present, a larger flux of HCH reached the sea. Presently, localised contamination of HCH in the sea is decreasing, but global contamination is increasing due to long-range atmospheric transport of residues from specific source areas.

Seasonal variation of persistent organochlorine insecticide residues, specifically HCH (BHC) and DDT, in water samples collected from Vellar River and Pichavaram mangroves in Tamil Nadu, South India, revealed higher levels of both HCH and DDT from October to February, with HCH exhibiting a more pronounced seasonal trend (Ramesh et al., 1990). The dominant HCH isomer was γ-HCH for all seasons, followed by β-HCH. Among DDT compounds, *p,p'*-DDT was the highest in river water, except during the dry season when *p,p'*-DDD showed a higher percentage. In the mangroves, *p,p'*-DDE was highest during the wet season, while *p,p'*-DDD dominated during the dry season. The study also revealed that HCH isomers and DDT compounds tended to be present in the water phase of the Vellar River. The presence of persistent pollutants, such as PCBs, HCH isomers, and DDT and its metabolites, in seawater and sediment samples from six locations along the east coast of India in the Bay of Bengal was studied using High-Resolution Gas Chromatography with High-Resolution Mass Spectrometer (HRGC-HRMS) for analysis (Rajendran et al., 2005). The results showed higher concentrations of all compounds in Chennai harbour and Cuddalore fishing harbour, with the highest concentration of total PCBs found in Chennai harbour sediment. Distinct patterns of PCB distribution were observed between harbours and other locations. HCH concentration was higher in seawater, whereas DDT levels were greater in sediments, particularly in urban areas, indicating local usage of this pesticide. Some coastal locations in the Bay of Bengal were designated as polluted by DDTs and g-HCH but not by PCBs, based on sediment and water quality criteria.

The study suggests a decreasing trend in the environmental burden of legacy persistent pesticides in the Indian marine environment. Levels of 17 OCPs in surface water and sediments of Tamiraparani (Thamirabarani). The Tamiraparani River basin in South India was assessed to elucidate the pollution in this perennial river system (Kumarasamy et al., 2012). Samples were collected from 12 sampling stations in four seasons during 2008-2009. The concentrations of ΣOCP in surface water ranged from 0.1 to 79.9 ng/l, while in sediments, they ranged from 0.12 to 3,938.7 ng/g dry weight (dw). DDTs, aldrin, dieldrin, cis-chlordane, trans-chlordane, and mirex were the dominant OCPs in sediments, whereas heptachlor, o,p'-DDE, dieldrin, o,p'-DDD, and mirex were dominant in water samples with different contamination patterns in different seasons. A recent study (Arisekar et al., 2021) focused on pesticide contamination in the Thamirabarani River, the only perennial river in Tamil Nadu, India assessed the distribution of pesticides and their potential ecological and human health risks. Variations in pesticide concentrations were observed in water, sediment and fish, with endosulfan, aldrin, and endrin being the predominant organochlorine pesticides present. The concentrations of pesticides in water and sediments were below acceptable thresholds, posing no significant ecological hazard to aquatic organisms. OCP analysis in green mussel (*Perna viridis*) and water samples from Ennore Creek, Chennai, was performed using gas chromatography with μ-ECD (Sundar et al., 2010). The results showed that mussel samples had very low concentrations of OCPs, with DDT being the highest (5.83 ng/g wet tissue), followed by endosulfan (2.84 ng/g wet tissue), and HCH (2.34 ng/g wet tissue). In water samples, the concentrations of OCPs were in the order of endosulfan (29.21 ng/L) > HCH (17.14 ng/L) > DDT (14.63 ng/L). This study is the first to report on the seasonal variation of OCPs in Ennore Creek and provides the quantification of endosulfan in the region. 19 OCPs in surface water and sediment from tanks located in agricultural areas of Kanyakumari district, Tamil Nadu, India, were analysed (Jeyakumar et al., 2014). A total of 36 surface water samples from 9 sampling sites and 27 sediment samples from 9 sampling stations were collected from these tanks, which served as water sources for cultivation. The concentrations of total OCPs in surface water ranged from 5.68 to 25.12 ng/L, while in sediments, it ranged from 17.7 to 58.59 ng/g dw. The most dominant compounds found in both sediment and surface water were hexachlorocyclohexanes (HCHs), dichlorodiphenyltrichloroethane (DDTs), and heptachlor epoxide. Among these, β-HCH, p,p′-DDD, and heptachlor epoxide were the dominant OCPs in sediment and water, respectively.

Human milk samples from Chennai, Perungudi, Chidambaram, and Parangipettai, all located near the south-eastern Bay of Bengal coast in India, for the presence of various organochlorine compounds showed measurable concentrations of HCHs, DDTs, PCBs, CHLs, and HCB in all the milk samples (Subramanian et al., 2007). A significant finding was that mothers from Chennai had higher levels of HCHs in their milk compared to mothers from the other three locations. This suggests a higher health risk for Chennai's children due to increased transfer of this chemical through breastfeeding. Moreover, the study revealed that the levels of HCHs and DDTs in Chennai mothers' milk have increased over the past decade. However, food items collected from Chennai markets did not exhibit remarkably higher levels of these chemicals, indicating the effectiveness of recent bans on HCHs and DDTs in the country. The study emphasises the need for further investigation into the sources, potential health risks, and ways to mitigate the effects of HCHs, especially in Chennai. Understanding and addressing these issues are crucial for safeguarding public health in the region.

Seasonal variations of OCP residues in air samples collected from Porto Novo, Tamil Nadu, South India, between December 1987 and January 1989 were focused on HCH (BHC) and DDT insecticides (Ramesh et al., 1989). The results indicated higher levels of both HCH and DDT from August to January, with HCH showing a more pronounced seasonal trend. γ-HCH was the dominant isomer for all seasons, followed by β-HCH. Among DDT compounds, p,p'-DDT was the highest, except during the dry season (January to April), when *p,p'*-DDE showed a higher percentage. In their study conducted in 2011, (Pozo et al., 2011) assessed seasonal and spatial trends of persistent organic pollutants (POPs) in Indian agricultural regions using PUF disc passive air samplers. They analysed samples collected from Ooty and Coimbatore in Tamil Nadu, India. Passive air sampling was conducted in different regions of Tamil Nadu, southern India, between April 2009 and January 2010 to investigate the distribution and fate of OCPs residues by (Srimurali et al., 2015). The study analysed 13 OCPs and found total concentrations ranging from ND to 41,400 pg/m^3. During the monsoon, DDT, DDE, heptachlor, and mirex were predominant. The elevated α/β isomer ratio of HCH during summer indicated fresh usage of HCH in the coastal area. Fresh application of dichlorodiphenyltrichloroethane was observed in all locations during the monsoon season, likely for vector control. The presence of banned pesticides like aldrin, dieldrin, and heptachlor in the air suggest illegal usage or old sources. Additionally, mirex, an unregistered pesticide in India, was detected in the air for the first time.

Levels of chlorinated insecticides in fish from the Bay of Bengal were studied by Rajendran et al., (2005)**.** The body burdens of environmentally persistent chlorinated insecticides such as DDT and its metabolites and HCH (BHC) isomers in 14 species of marine fish collected from Tamii Nadu (Madras, Cuddalore, Nagapattinam, and Tuticorin) and Pondicherry coasts of the Bay of Bengal in South India were reported. The total HCH was more dominant than total DDT. Moreover α-HCH and *p,p'*-DDT were greater among HCHs and DDTs respectively. Higher concentrations of both the compounds were detected in the tissues of rays (*Dasyatis sp*.), *Lares calcarifer, Scomberomorus guttatus,* and *Nemipterus japonicus*. The study conducted by (Rajendran et al., 1992), focused on the levels of chlorinated insecticides in fish from the

Bay of Bengal. They analysed 14 species of marine fish collected from various coasts in South India. The study reported higher levels of environmentally persistent chlorinated insecticides, specifically DDT and its metabolites, and HCH (BHC) isomers. Total HCH was found to be more dominant than the total DDT. Among HCHs, a-HCH was greater, while *p,p'*-DDT was higher among DDTs. Rays *(Dasyatis sp.), Lares calcarifer, Scomberomorus guttatus*, and *Nemipterus japonicus* showed higher concentrations of both compounds in their tissues. The study by (Muralidharan et al., 2009) investigated the presence of organochlorine pesticide residues in 10 species of commercially available marine fish sold in Coimbatore, Tamil Nadu, India. They analysed a total of 389 fish samples and found varying levels of residues of hexachlorocyclohexane (HCH), DDT, heptachlor epoxide, endosulfan, and dieldrin. Some species, such as *Sardinella longiceps, Carangoides malabaricus, Chlorophthalmus agassizi, Saurida tumbil*, and *Rastrelliger kanagurta*, showed high concentrations of pesticide residues. The study revealed monthly variation in residue levels in some fish species but no significant correlation between body size and residue levels. Approximately 22% of the fish exceeded the maximum residue limits (MRL) of total HCH prescribed by FAO/WHO for fish products. (Sundhar et al., 2021) evaluated the presence of OCPs in various seaweed species along the Thoothukudi coast in Tamil Nadu, India. They found higher OCP concentrations at one site compared to others, with *Sargassum wightii* showing the highest accumulation. The study identified *S. wightii* as a potential biomonitor for OCP residues in the marine environment, except for endosulfan. The findings highlight the species-specific nature of pesticide accumulation in seaweeds and their potential as indicators of pesticide contamination.

(Devanathan et al., 2009) conducted a study on persistent organochlorines in human breast milk from major metropolitan cities in India. (Murugasamy et al., 2021) analysed the distribution of polychlorinated dibenzo-p-dioxins/polychlorinated dibenzofurans (PCDD/Fs) and dioxin-like polychlorinated biphenyls (DL-PCBs) in bovine milk and ash samples collected from major districts in South India (Tamil Nadu). The total toxic equivalency (TEQ) for PCDD/Fs and DL-PCBs in the bovine milk samples ranged from 0.028 to 7.331 pg TEQ/g fat. Some districts showed higher contamination levels in both milk and ash samples, with certain sampling sites exceeding WHO regulation limits. The study highlights dioxin and dioxin-related compound contamination in the region and the usefulness of the CALUX assay for environmental monitoring of dioxins.

Odukkathil & Vasudevan (2016) conducted an evaluation study in Chennai during 2002 to 2004 using 12 breast milk samples. In this study, the researchers investigated pesticide residues in the surface and subsurface soil in Pakkam Village, Thiruvallur District, Tamil Nadu, India, which is an area with intensive agricultural activity. They collected soil samples from different layers and analysed the pesticides present. The results showed that alpha endosulfan and beta endosulfan concentrations were highest in the surface soil, ranging from 1.42 to 3.4 mg/g and 1.28 to 3.1 mg/g, respectively. In the subsurface soil (15-30 cm), the concentrations were lower, ranging from 0.6 to 1.4 mg/g for α-endosulfan and 0.3 to 0.6 mg/g for β-endosulfan. In the subsurface soil (30-40 cm), the concentrations were 0.9 to 1.5 mg/g for α-endosulfan and 0.34 to 1.3 mg/g for β-endosulfan. (Murugan & Vasudevan, 2017) investigated the contamination of soil with persistent organic pollutants (POPs) and heavy metals resulting from transformer oil spillage. They analysed both fresh and used transformer oil samples along with soil samples from 10 contaminated sites, confirming the presence of PCB congeners, PAHs, phenolic compounds, and heavy metals. The researchers used various analytical methods, including principal component analysis, metric multi-dimensional scaling, and Bray-Curtis cluster analysis, to study the variation in pollutant concentrations among different sampling sites.

Chakraborty et al. (2010) conducted a study in seven metropolitan cities, including Chennai, and found local/regional sources of OCPs, with Chennai contributing significantly. Similarly, Chakraborty et al. (2013) measured atmospheric concentrations of PCBs in seven major cities, including Chennai, and attributed the sources to electronic waste, ship-breaking activities, and dumped solid waste. Furthermore, Chakraborty et al. (2015) quantified selected OCPs in soil samples from urban, suburban, and rural transects in seven major Indian cities, including Chennai, and assessed the air-soil exchange, revealing a continuous cycle of emission and re-emission of OCPs from Indian soil for years to come. Srimurali et al. (2015) conducted passive air sampling in Tamil Nadu and reported elevated levels of DDT, DDE, heptachlor, and mirex, with the isomer ratio of HCH suggesting fresh/recent usage in coastal areas. Additionally, high concentrations of PCBs were observed in settled dust from informal electronic waste recycling workshops and industrial roadsides in Chennai city (Chakraborty et al., 2016a). The major metropolitan cities in India, including Chennai, have been identified as hotspots for PCB emissions, with ongoing sources like e-waste activities, ship-breaking activities, open burning in dumpsites, and industrial activities (Chakraborty et al., 2016b). Furthermore, Chakraborty et al. (2017) conducted passive air sampling along urban-suburban/rural transects in four quadrilateral cities, including Chennai, and demonstrated elevated levels of PBDEs. High concentrations of PCBs and PCDD/Fs were reported in Chennai soil from e-waste recycling sites and dumpsites, indicating ongoing PCB sources (Chakraborty et al., 2018). Chakraborty et al. (2019) evaluated seasonal variations of atmospheric OCPs and PBDEs in Parangipettai, Tamil Nadu, and suggested that regional atmospheric transport from metropolitan cities like Chennai could be a significant contributor to atmospheric PBDEs in remote regions. Additionally, Prithiviraj and Chakraborty (2020) studied atmospheric PCBs from an urban site near an informal electronic waste recycling area and a suburban site in Chennai city, identifying open burning in municipal dumpsites and e-waste recycling by informal sectors as major sources. Furthermore, Chakraborty et al. (2021) conducted passive air sampling of various pollutants, including dl-PCBs, near informal electronic waste recycling sites in Chennai and Bangalore, revealing high estimated inhalation risks for dl-PCBs for youth at the e-waste transect. Selvaraj et al. (2021) investigated legacy POPs and PAHs in the surface soil from the industrial corridor of Tamil Nadu and found evidence of recent contamination, with soil acting as a sink for organic contaminants. Rajan et al. (2021) conducted an in-depth study on surface soil concentrations of PCDD/Fs, PCBs, and PAHs in major municipal dumpsites in Chennai, and they revealed that burning of municipal waste in dumpsites is a major contributor to the release of toxic POPs and PAHs. Amid the COVID-19 pandemic, Rex and Chakraborty (2022) observed variations in OCPs and PCBs in surface water samples from rivers in Chennai, indicating a significant increase in PCB-52 during the pandemic and a subsequent reduction in dl-PCBs in riverine water after the lockdown in the city. Ramalingam et al. (2021) found that environmental exposure to various OC and organophosphate pesticides is associated with prevalent type-2 diabetes in the Indian population, supported by other published literature implicating OCPs in diabetes risk.

Per- and polyfluoroalkyl substances (PFASs) are widely used in many industrial and domestic applications, such as fluoropolymers, liquid repellents for paper, leather, carpet goods, electronics manufacturing, metal plating, lubricants, nonstick-cookware, water- and greaseproof textiles, food packaging materials, protective coatings, and firefighting foams (Clara et al., 2008; Dauchy., 2019). PFASs released into the environment as direct and indirect sources (Prevedouros et al., 2006). Direct sources of PFASs are ingredients and/or impurities from the manufacturing process, while indirect processes refer to the degradation products (Wang

Table 2.1: Level of perfluorinated compounds in rivers from South India

Place/Country	ΣPFAS (ng/L)	PFOA (ng/L)	PFOS (ng/L)	PFHxs (ng/L)	Reference
Cooum River		23.1	3.91		(Yeung et al., 2009)
Rivers in Tamil Nadu		4-93	3-29		(Sunantha & Vasudevan, 2016)
South Indian Rivers	1.853±1.463	0.645±0.415	0.420±0.233	0.447±1.030	(Selvaraj et al., 2021)

et al., 2014). Among PFAS, PFOS, its salts, and PFOSF were included under Annex B of the SC for restriction in 2009, PFOA, its salts, and PFOA-related compounds were included in Annex A of the Convention for elimination in 2019, and PFHxS in Annex A in 2021 due to their ubiquitous, persistent, bioaccumulative, and toxic nature. The flux carried by Cauvery and Tamiraparani rivers was 15 kg/yr and 2.2 kg/yr of perfluorinated compounds into the Bay of Bengal (Selvaraj et al., 2021).

2.3.2 Status of new POPs in the study region (Tamil Nadu)

The listing of the chemicals as POPs is a continuous process in the Stockholm Convention. The Convention has listed 12 chemicals (dirty dozen) into Annex A (complete elimination) since 2004. Subsequently, all the other POPs added to the list from 2009 (e.g., HCH, etc.) were classified as 'New POPs'. In 2023, three new compounds— methoxychlor, Dechlorane Plus, and UV-328—were added to this expanding list. Since promulgation of the National Implementation Plan (NIP) in 2011, India has completely banned 7 out of the 20 new POPs and restricted the use of others **(Table 2.2)**.

Tamil Nadu is the second-largest economy in the country and a highly industrialised state. In 2021 –2022, it accounted for 9.2% of India's total GDP (Rangarajan & Shanmugam, 2023). Service, manufacturing, and agriculture are major economic activities in the state. It houses a few of the biggest manufacturing hubs of automobiles (Chennai), leather (Erode), chemicals (Thoothukudi), dyes, and textiles (Tirrupur) in the country. Many of these industries use POPs as input chemicals for manufacturing (UV-328) or release pollutants in the form of hazardous by-products (Pentachlorobenzene). Poly- and perfluoroalkyl compounds (PFAS) are used in the production of automotive parts (hydraulic breaks, batteries, fuel lines, lubricants, etc.) and construction materials (roofs and coating) (NIOSH, 2024); POPs such as UV-328 are also used in construction of exterior and interior part of vehicles, in addition to cosmetics, medical devices and plastic additives (ECHA, 2024). DecaBDE, polychlorinated naphthalene (PCN) and SCCP are flame retardants and plasticisers that are used in various other manufacturing industries in the state. The textile and tanning industries use pentachlorophenol as disinfectants (Mou et al., 1999), and biocides like endosulfan, HCH, and methoxychlor (a DDT alternative) are used for pest management (details in Chapter 2.1). Some other examples are given below:

There is a lack of state-specific data on the consumption and stockpiles of these new POPs. Therefore, research studies are vital to map the mobilisation of emerging POPs through environmental matrices. It is a great tool to identify the source, fate, and behaviour of the organic pollutant across different environmental matrices. Some of the studies are summarised in **Table 2.3**.

Research studies have detected POPs at major river systems, soil, groundwater and sewage treatment

Table 2.2: Regulatory status of New POPs in India

S. No.	POPs	Category	Uses	Status in Tamil Nadu (based on scientific data)
1	α– hexachlorocy-clohexane (αHCH)	Pesticides/ by-products (lindane)	It is one of the isomers of HCH, a by-product of the production of the insecticide lindane.	No laws and policies or legislation currently in place for these POPs. The studies have detected agricultural patches and areas where lindane is applied against vector-borne diseases.
2	β– hexachlorocy-clohexane (βHCH)	Pesticides/ by-product (lindane)	It is one of the isomers of HCH, a by-product of the production of the insecticide lindane.	No laws and policies or legislation currently in place for these POPs. The studies have detected it around agricultural patches and areas where lindane is applied against vector-borne diseases.
3	Chlordecone	Pesticides	Used to control banana root borer, fly larvicide, as a fungicide against apple scab, powdery mildew, rust mite, and protection of other plants. It can also be used in household products such as ant and roach traps.	National ban for manufacture, use, import, export, and disposal of waste since 2018.
4	Decabromo-diphenyl ether (decaBDE)	Industrial chemical	Used as an additive flame retardant and has a variety of applications in plastic, polymers, composites, textiles, adhesives, sealants, coatings and inks. DecaBDE-containing plastics are used in housing for computers and TVs, wires and cables, pipes, and carpets.	E-waste Management Rules (2016) allows the use of polybrominated diphenyl and polybrominated biphenyl ethers only at 0.1% by weight in homogenous materials for electrical and electronic products. Suspected use in the textile, chemical, and electronics industries.

S. No.	POPs	Category	Uses	Status in Tamil Nadu (based on scientific data)
5	Dechlorane Plus*	Industrial chemical	It is polychlorinated flame retardant that is used in electrical wire, cable-coatings, plastic roofing materials, connectors in TVs and computer monitors.	No laws and policies or legislation currently in place to regulate this POP chemical. Use suspected in the Electronics industry
4	Dicofol	Pesticides	It is an organochloride miticidal pesticide that has been used on field crops, fruits, vegetables, ornamentals, cotton, tea, etc.	On 15 February 2023, the Ministry of Agriculture passed a draft order, "Insecticide (prohibition) Order 2023" proposing a ban on dicofol. This was a follow-up from the draft notification "Banning of Insecticides Order, 2020" (S.O. 1512(E)). Use suspected in agriculture.
5	Endosulfan	Pesticide	It was used as an insecticide for the control of aphids, thrips, beetles, foliar feeding larvae, mites, borers, cutworms, bollworms, whiteflies, and leafhoppers. It was sprayed on a variety of crops.	Banned by the Supreme Court on 13th May 2011. Finally disposed of dates 10th January 2017 Apart from the rare illegal agricultural applications, application on crops does not occur.
6	Hexabromo-biphenyl	Industrial chemical	It is used as a fire retardant in acrylonitrile-butadiene-styrene (ABS) thermoplastic for construction businesses, machine housings, industrial and electrical products, and also in polyurethane from auto upholstery.	Nation-wide ban on manufacture, use, import, export, etc. since 2018. There are no reports of its use. Environmental concentration was also not reported.

S. No.	POPs	Category	Uses	Status in Tamil Nadu (based on scientific data)
7	Hexabromocyclododecane (HBCDD)	Industrial chemical	HBCDD is a flame-retardant additive that provides fire protection during the service life of vehicles, buildings, or articles. It is mainly used in expanded and extruded polystyrene foam insulation.	Banned for manufacture, use, import, export, etc. since 2018. Environmental concentration was also not reported by research. There is a possible use in the automobile, chemical, and textile industries.
8	Hexabromo-diphenyl ether and heptabromo-diphenyl ether	Industrial chemical	It is used as a main component of commercial octabromodiphenyl ether production. These synthetic brominated compounds are used as flame retardants.	Banned for manufacture, use, import, export, etc. since 2018. There are no reports of its use in the state. Environmental concentration was also not reported by recent research studies.
9	Hexachloro-butadiene (HCBD)	By product	It is commonly used as a solvent for chlorine-containing compounds. It is used as a scrubber to recover chlorine-containing gas or to remove volatile organic components from gas; hydraulic, transformer fluid; in the production of aluminium and graphite rods.	Banned for manufacture, use, import, export, etc. since 2018. There are no reports of its use in the state. Suspected use in chemical industry, electrical industry, and automobile industry. HCBD is also produced unintentionally during the manufacture of chlorinated aliphatic compounds.
10	Lindane	Pesticides	The compound has been used as a broad-spectrum insecticide for seed and soil treatment, foliar applications, tree and wood treatment, and against ectoparasite in both veterinary and human applications.	Banned for manufacture, use, import, and export w.e.f. 25th March 2011 and banned for use w.e.f. 25th March 2013. In rare cases, it is used in agricultural fields as pesticides and against vector-borne diseases

S. No.	POPs	Category	Uses	Status in Tamil Nadu (based on scientific data)
11	Methoxychlor*	Pesticides	It is used to protect crops, ornamentals, livestock and pets against fleas and other insects. It was intended to replace DDT.	No laws and policies or legislation currently in place for these POPs. It is also not registered under the Insecticides Act 1968. (Directorate Plant Protection, Quarantine and Storage, 2024c) Suspected use in agriculture and/or public health protection from vector-borne diseases.
12	Pentachloro-benzene (PeCB)	Pesticides/ by product	It is added to PCB products, in dye carriers, as a fungicide, a flame retardant, and as a chemical intermediate, e.g., previously for the production of quintozene.	Banned for manufacture, use, import, export, etc. since 2018. Suspected use in textile and dye and chemical industry.
13	Pentachlorophenol and its salts and esters	Industrial chemical/ pesticides	It is used as an herbicide, insecticide, fungicide, algaecide, disinfectant, and as an ingredient in antifouling paint.	Banned for use in agriculture (exact date not available) (Directorate of Plant Protection, Quarantine & Storage, 2023) but is allowed for other industrial purposes such as wood preservatives. Suspected use in the leather and paper mill industries.
14	Perfluorohexane sulfonic acids (PFHxS)-related compounds	Industrial chemical	The compound has been used in aqueous film-forming foams for firefighting, metal plating, textiles, leather, upholstery, polishing agents, cleaning/washing agents, etc.	No laws and policies or legislation currently in place for these POPs. Suspected use in chemical, textile, leather, paint, electronics, and semiconductor industry.

S. No.	POPs	Category	Uses	Status in Tamil Nadu (based on scientific data)
15	Perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOSF)	Industrial chemical	Commonly used as flame retardants and incorporated as salts into larger polymers. They are also used in firefighting foams, carpets, leather/ apparel, paper and packaging, coatings, and their additives, and many other industries.	Suspected use in automobile, chemical, and textile industries. It can also be used in the aerospace and semiconductor industries.
16	Perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds	Industrial chemical	It is used widely in fluoroelastomers and fluoropolymers to produce non-stick products like kitchen products. PFOA-related compounds can be found in textiles, paper and paints, and fire-fighting foams.	BIS announced on 28th September 2020 that it would adopt the PFOS and PFOA and PFOA International Standards Organisation (ISO) benchmarks as India Standards (IS), but it has not been notified yet. It could be used in the chemical, textile, paper, and manufacturing companies specialising in non-stick products for kitchenware. It is also released into the environment through the incineration of fluoropolymers and fluoroelastomers.
17	Polychlorinated napthalenes	By product	It is used to make effective insulating coatings for electrical wires and others. It is also used as storage batteries, capacitors, and in lubricants.	It is banned in printing ink for food packaging (2004) under BIS standard IS 15495:2004 Suspected use in the electronic industry

S. No.	POPs	Category	Uses	Status in Tamil Nadu (based on scientific data)
18	Short-chain Chlorinated paraffins (SCCPs)	Industrial chemical	SCCPs are used primarily in metalworking applications. Other uses include flame retardants or plasticisers in PVC, paints, adhesives, sealants in buildings, car carpet, textiles, and other polymers.	No laws and policies or legislation currently in place for these POPs. Considering the versatility of the chemical, it's suspected to be used in multiple industries like textile, chemical, electronics etc.
19	Terabromo-diphenyl ether and pentabromo-diphenyl ether (commercial pentabromo-diphenyl ether)	Industrial chemical	It is used as a commercial pentabromodiphenyl ether mixture (C-PentaBDE) for flame retardant purposes as additives in consumer products.	Banned for manufacture, use, import, export, etc. in 2018. Suspected use in car, textile, and electronics industries.
20	UV-328*	Industrial chemical	It is used as a light stabiliser for a variety of plastics and other organic substrates.	No laws and policies or legislation currently in place for these POPs. Use industries such as automotive, paints and inks, etc. is suspected

plants (STPs). Chemicals such as PCP, PFAS, and UV-328 were detected in areas surrounding hubs like Chennai, Coimbatore, and Erode. Noyyal, a tributary of the Cauvery, which flows past 729 bleaching and dying units in Tirupur, had traces of PFOS and PFOA in it (Rajkumar & Nagan, 2011). Seeing the continuous decline in the water quality, the state government established the Zero Liquid Discharge (ZLD) norms in 2011 for tanneries and distilleries. But this could not cause significant changes to the situation as high costs for the technology became a hurdle in the proper implementation (Vijayanandan et al., 2023).

Not all exposure is a result of intentional use; chemical impurities (α, β - HCH, HCB, PeCP), seasonal movement due to atmospheric changes (Endosulfan from Kerala), and mismanagement of waste are also contributing factors to the release and emission of POPs in the environmental matrices.

India has taken numerous steps towards tackling issues related to the use and disposal of POPs—ratifying the Stockholm Convention in 2016, establishing E-waste management rules, and banning seven new POPs in 2018 while restricting and phasing out others. There are many studies

Table 2.3: Detection of New POPs according to recent studies in Tamil Nadu

POPs	Category	Matrices	Study location	References
Dicofol	Pesticide	Tea, vegetable (green chillies)	Coimbatore region	(Vijayalakshmi et al., 1998); (Rajukannu et al., 1981)
PBDE (E.g., DecaBDE, PentaBDE)	Industrial chemical	Air	Chennai	(Zhang et al., 2008)
Endosulfan	Pesticide	Air, Soil, Ground water, Fish	Parangipettai, Kancheepuram, Tirunelveli district, Sivagangi district, Nazarath, Othikadu, Ekkadu and Ekkadukandigai, Thiruvallur district	(Jayashree & Vasudevan, 2007); (Chakraborty et al. 2018); (Samidurai et al. 2019); (Ashesh et al. 2022); (Sundhar et al 2023)
Hexabromobiphenyl	Industrial chemical	Air	Chennai region	(Chakraborty et al., 2010., 2017)
Hexachlorocyclohexane	Pesticide	Birds, Sediment, Surface Water, Soil	Chennai, Chengalpattu, Tirunelveli district, Sivagangi district, Cauvery River, Coimbatore, Nilgiris, Erode, Dharmapuri, salem, Namakkal, Salem, Dindigul	(Patil et al., 2015); (Samidurai., et al. 2019); (Venugopal et al., 2020); (Ashesh et al., 2022); (Rex & Chakraborty, 2022); (Sundhar et al., 2023)
Methoxychlor	Pesticide	Fish, River water	Thamirabarani	(Arisekar et al., 2021); (Sundhar et al., 2023)
Perfluorohexane Sulfonic acid (PFHxS)	Industrial chemical	Human hair	Kanchipuram	(Ruan et al., 2019)
PFOS	Industrial chemical, pesticide	Human hair, Surface water, Road dust	Kanchipuram, Noyyal, Cauvery, and lakes around Chennai. Chennai and Kanchipuram. Cauvery, Vellar and Tamiraparani	(Ruan et al., 2019); (Sunantha & Vasudevan, 2016); (Selvaraj et al., 2021)

POPs	Category	Matrices	Study location	References
PFOA	Industrial chemical	Human hair, Surface water, Road dust	Kanchipuram, Noyyal, Cauvery and lakes around Chennai. Chennai and Kanchipuram; Cauvery, Vellar and Tamiraparani	(Ruan et al., 2019); (Sunantha & Vasudevan, 2016)
Polychlorinated naphthalene	Industrial chemical	Air	Chennai	(Xu et al., 2014)
Short-chain chlorinated paraffins (SCCPs)	Industrial chemical	Air	Chennai	(Chaemfa et al., 2014).
UV-328	Industrial chemical	Surface water, sediment, and fish; STPs	Cauvery, Vellar, Thamiraparani	(Vimalkumar et al., 2018); (Vimalkumar et al., 2022)

**Only studies from the last 8 years were considered (2015-2023)*

which indicate the presence of both the new and old POPs in various environmental matrix in Tamil Nadu. Therefore, there is a need of generating state-specific compressive data to enhance the understanding of the current situation on POPs consumption and release for their better management both in Tamil Nadu and India.

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Chapter 3
DESCRIPTION OF PILOT CATCHMENT AREAS OF CAUVERY RIVER BASINS

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3.1 Physical characteristics

3.1.1 Introduction

The Cauvery River is one of the major rivers in Peninsular India. It rises in the Kodagu district of Karnataka at an elevation of about 1341 m. It falls in the Bay of Bengal in Tamil Nadu after travelling about 800 km in the South-East direction of 75°27' to 79°54' E and 10°9' to 13°30' N. The length of the river that passes through Tamil Nadu is 416 km. The total catchment area of the basin is 87,900 km^2 and 43,856 km^2 in Karnataka and Tamil Nadu, respectively. Hydrologically, the Cauvery River is the primary watercourse that flows through the basin. The Cauvery Basin spans across the states of Kerala, Karnataka, Tamil Nadu, and the Union Territory of Puducherry. The distribution of its basin area is as follows: 42% in Karnataka, 54% in Tamil Nadu, including the Karaikkal region of Puducherry, and 4% in Kerala (WRIS, 2014).

The Cauvery River Basin's hydrology is mainly influenced by monsoon rains, especially the

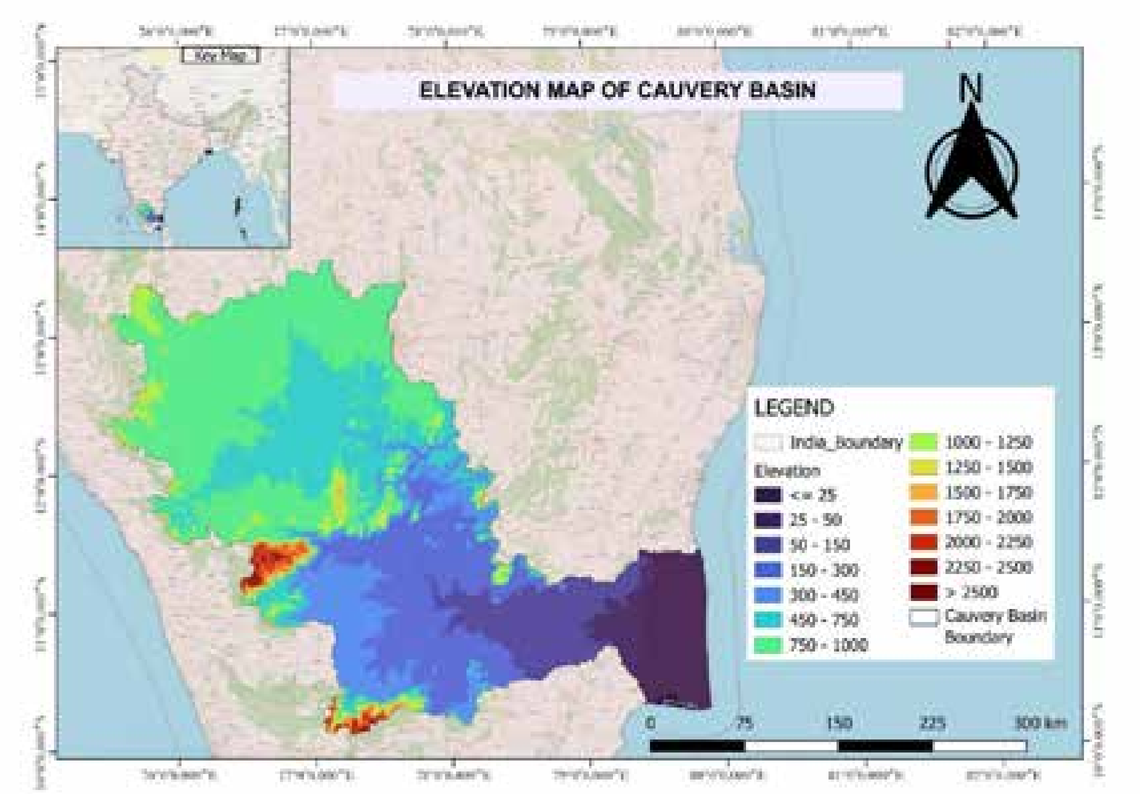

Figure 3.1: Elevation map for Cauvery basin

[1]SRM Institute of Technology, [2]Mu Gamma Consultants (MGC)

southwest monsoon from June to September. This rainfall sustains the river and its tributaries, including the Hemavati, Shimsha, Arkavati, Kabini, Bhavani, and Amaravati. The basin's terrain is diverse, starting with the Western Ghats forming its western boundary, a UNESCO World Heritage Site known for its dense forests, biodiversity, and waterfalls, and the Eastern Ghats forming the Eastern and Southern boundary, and the basins of the Pennar and the Krishna rivers bounding the North (WRIS, 2014).

As the river moves eastward into the Deccan Plateau, the landscape becomes undulating and fertile plains, supporting agriculture like rice, sugarcane, and millets. The basin also features reservoirs and dams like the Krishna Raja Sagara and Mettur Dam, aiding in water storage, flood control, and hydroelectric power generation. In Tamil Nadu, the Cauvery River is vital for water resources, with the Mettur Dam regulating its flow. The Cauvery Delta, a fertile region characterised by flat terrain and alluvial soils, is a major rice producer and is referred to as the "*Rice Bowl of Tamil Nadu.*" The river and an extensive canal network are essential for irrigation in this region. Apart from agriculture, the Cauvery River and its delta support biodiversity and ecological balance, with wetlands and backwater areas serving as critical habitats for migratory birds. The network of tributaries and distributaries enhances hydrological dynamics and agricultural productivity in the Tamil Nadu portion of the basin.

3.1.2 Topography

The river basin can be divided into three physiographical parts: the Western Ghats, the Plateau of Mysore, and the Delta. The elevation of the basin ranges from 2 meters to 3000 meters. The Western Ghats, which border the left side of the river basin, have the highest elevations. As the river flows east, it descends from the South Karnataka plateau to the Tamil Nadu plains through waterfalls. The predominant rock types are igneous and metamorphic. The eastern deltaic area is characterised by alluvial soil. The principal soil types found in the basin include red, black, laterite, alluvial, forest, and mixed soils. Red soils are the most prominent. Peninsular Gneiss largely covers the basin, followed by Charnockite, recent alluvium, Dharwars, Cretaceous limestone, and granite (Arulbalaji, 2019).

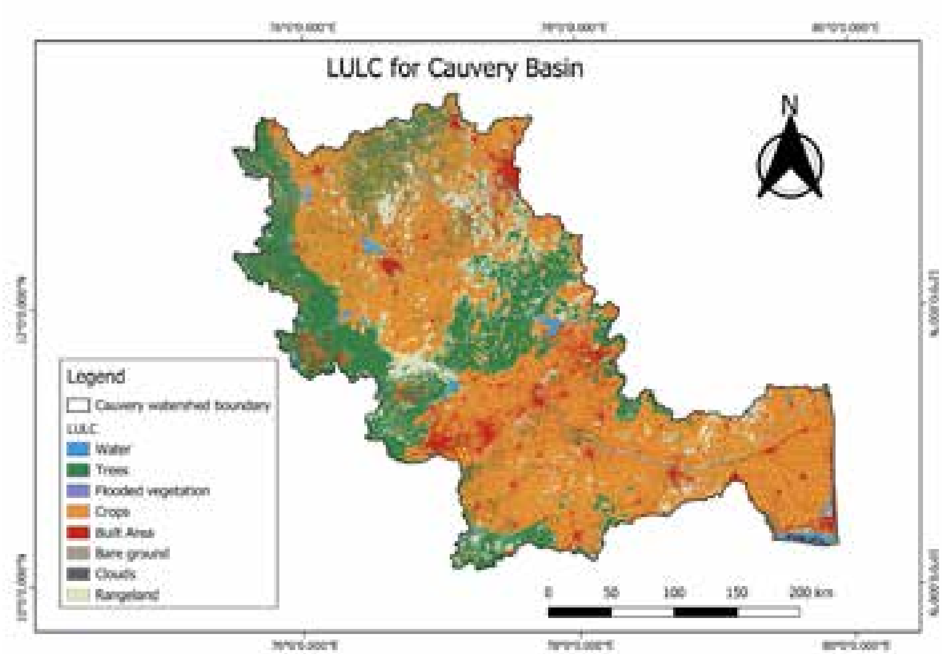

Figure 3.2: LULC Map of Cauvery Basin using ESRI 10-m resolution

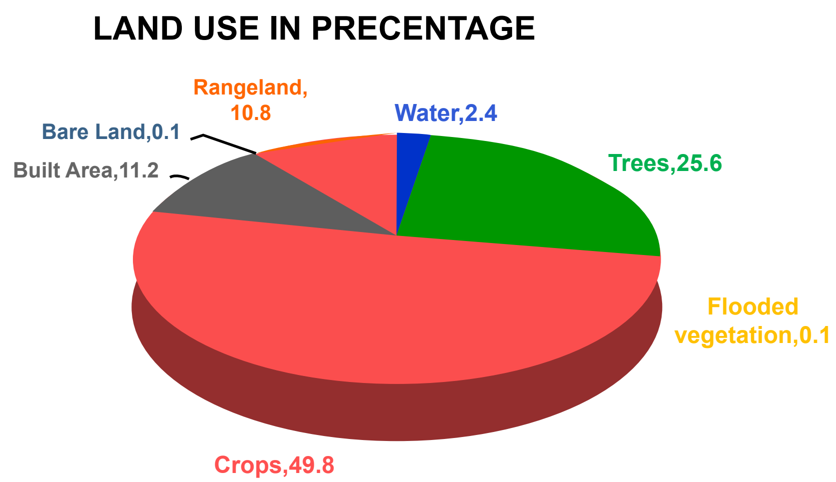

Figure 3.3: Land use in percentage for Cauvery watershed

3.1.3 Land Use Land Cover

The alteration in Land Use and Land Cover (LULC) stands as a significant factor that detrimentally influences the physical, chemical, and biological characteristics of a river basin (Kumaraswamy et al., 2021). In this context, an ESRI 10-meter resolution LULC map for the year 2022 serves as the foundation for LULC classification. Notably, the analysis reveals a predominant coverage by crops, i.e., agricultural land, encompassing approximately 50% of the area. Following this, forested areas, potentially lying between the Mysuru plateau and Tamil Nadu plains, are represented as tree-covered regions. Furthermore, the fertile delta region at the river's mouth is acknowledged for its prolific rice production.

In terms of urbanisation, notable cities such as Bengaluru, Mysuru, Coimbatore, and Tiruchirappalli contribute to the expanding built-up areas depicted in red. Over the last few years, the urban developmental pattern of the river basins shows the rapid growth of Tire-I and Tire-II cities, primarily because of enhanced transportation facilities and waterbodies, leading to habitat fragmentation (Kumaraswamy et al., 2021).

3.1.4 Hydrological Characteristics

The utilisable surface water resource available for the basin is estimated to be 19 billion cubic meters (BCM). The average annual runoff and average annual water potential within the basin are recorded as 21.36 BCM (WRIS, 2014).

The basin is characterised by three distinct sub-basins: the upper Cauvery basin, composed of the Western Ghats; the middle Cauvery basin, encompassing the Mysuru Plateau; and the lower Cauvery basin, which includes the Tamil Nadu plains and the Delta region.

The major left bank tributaries of the Cauvery River are the Harangi, the Hemavati, the Shimsha, and the Arkavati, and the major right bank tributaries are the Lakshmantirtha, the Kabbani, the Suvarnavati, the Bhavani, the Noyil, and the Amaravati.

Tributaries:

Bhavani River: One of the major tributaries of the Cauvery, the Bhavani River originates in the Nilgiri Hills of Tamil Nadu. It flows through the western part of the state before joining the Cauvery near the town of Bhavani. The Bhavani River is vital for water supply and irrigation in the districts of Erode and Tiruppur.

Amaravati River: Another significant tributary, the Amaravati River originates in the Anaimalai Hills in Tamil Nadu and flows through the districts of Karur

Figure 3.4: Major tributaries of Cauvery (*Google Images*)

and Dindigul. It meets the Cauvery River in the district of Tiruchirappalli (Trichy). The Amaravati River contributes to the irrigation needs of the region and is important for supporting agriculture.

Noyyal River: Though not a direct tributary of the Cauvery, the Noyyal River feeds into the Bhavani River, which, in turn, joins the Cauvery. The Noyyal River originates in the Western Ghats and flows through the districts of Coimbatore and Tiruppur. It is significant for its historical importance as well as its contribution to the region's water resources.

Distributaries:

Coleroon River (Kollidam): After the Cauvery River flows through Tamil Nadu, it bifurcates into two distributaries. One of these is the Coleroon River, also known as Kollidam, which branches off near Grand Anicut (Kallanai) in the district of Thanjavur. The Coleroon River runs parallel to the Cauvery and ultimately empties into the Bay of Bengal near the town of Poompuhar. It is an essential distributary that helps in diverting water away from the main river, contributing to irrigation and flood management.

Vennar River: The Vennar River is another significant distributary of the Cauvery, branching off from the main river near Grand Anicut (Kallanai). It flows through the districts of Tiruchirappalli and Pudukkottai, ultimately joining the Bay of Bengal. The Vennar River, along with other distributaries, plays a vital role in maintaining water balance and supporting agriculture in the delta region.

These tributaries and distributaries form an intricate network of waterways that ensure the efficient distribution of water throughout the Tamil Nadu portion of the Cauvery River Basin. They contribute to agricultural irrigation, water supply for domestic and industrial use, and help in managing floods during the monsoon season. The proper management and conservation of these waterways are crucial for sustaining the agricultural productivity and ecological balance of the region.

3.1.5 Meteorological Features

Rainfall: The main source of runoff is the rainfall. The basin receives rainfall mainly from the South-West monsoon in the Karnataka region and partially from North-East monsoon in Tamil Nadu (WRIS).

Temperature: The basin experiences a dry climate except in the monsoon months. The mean daily maximum temperature in the basin varies from 19.5°C to 33.7°C, and the mean daily minimum temperature varies from 9.10°C to 25.2°C (NWDA, 2020).

Wind speed: In the monsoon, the wind follows the direction of monsoon winds. During the rest of the year, wind blows from the direction between north and east. The mean wind speed in the basin varies from 5.4 km/hr to 18.9 km/hr (NWDA, 2020).

Humidity: The relative humidity in the basin ranges from 49% to 86% (NWDA, 2020).

3.2 Socioeconomic context: Demography & other relevant socio-economic features

The catchment of the river basin lies in the states of Karnataka, Tamil Nadu, Kerala, and Union Territory of Pondicherry. Of the total area of the basin, 41.2% falls in the state of Karnataka, 55.5% in the state of Tamil Nadu, and 3.3% in Kerala. The width of the basin ranges from 65 to 250 km. The total length of the river from its source to its outfall in the Bay of Bengal is about 800 km, of which 320 km are in Karnataka and 416 km in Tamil Nadu. Its substantial, fertile alluvial plains and low hills, along with favourable climatic conditions, provide ideal conditions for using the land for a variety of purposes. Arable, non-arable, forest land, and land for habitation are the four different types of land-use patterns identified in the basin. Over 50% of the land is arable or cultivable, compared to 21.6% non-arable, 19.53% forest, and the remaining territory, which is inhabited and divided between rural and urban areas. Rural areas are home to more than 50% of the population, with agriculture being the primary occupation (Chidambaram et al., 2018). The land use pattern of the basin witnessed a change in the last few decades. The fast-growing population, aided by modern technology, has led to rapid change in the land use pattern of the basin. The effect is reflected in the form of ecological imbalance and land degradation through soil erosion. The forest area has been decreasing due to the encroachment for agricultural use. The horizontal growth of settlement in the last few decades due to the rapid growth of population and the resultant growth of other developmental activities also led to a slow but continual change to the land use pattern at different scales

In the pursuit of optimising the economic benefits from channel flow, the investment in water-related development tends to overlook the importance of maintaining the quantity and quality of water for supporting the ecosystem's supporting services (Baron et al., 2002; Poff et al., 2010; Poff et al., 2012). Climate change is expected to impact the hydrological cycle, which could have a profound impact on water availability for humans and aquatic ecosystems (Thompson et al., 2014). Changes in water availability due to either climate change or

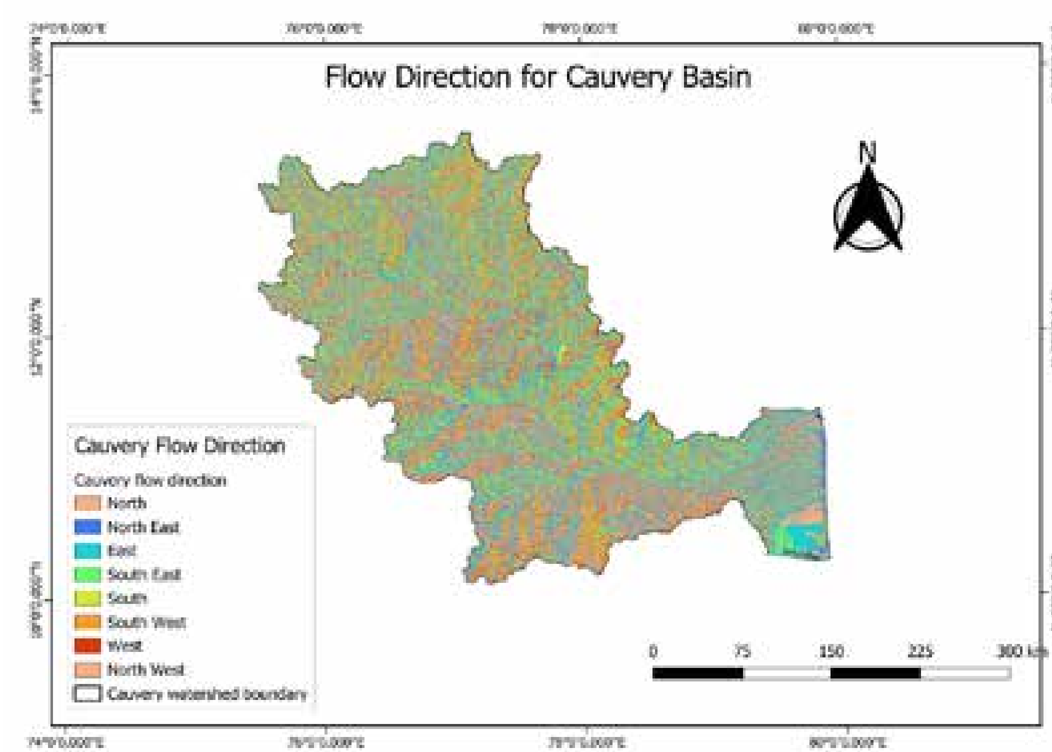

Figure 3.5: Flow direction map of Cauvery basin using 30-m SRTM DEM data

prompted by human activities have a direct and abrupt impact on both the food and energy sectors (Karabulut et al., 2016). Changes in land-use and land-cover and rate of population growth have been predicted for various socio-economic pathways, which induce further uncertainty in the regional water resource availability and hydrological regime (Gupta, Horan, et al., 2022).

3.2.1 Demographic characteristics

Based on the 2011 Census, the total population in this basin is about 3,18,89,280.

3.2.2 Importance of the Cauvery River in Southern India.

Cauvery water is mainly used for irrigation purposes, domestic purposes, and power generation. It was estimated that the river's average annual flow amounted to 7.5 km^3 (Gupta, Reddy et al., 2022). With three major reservoirs and a number of weirs and anicuts built across the river and its tributaries, Cauvery is the most exploited river of the country (95% abstraction of water) (Chidambaram et al., 2018). Bangalore receives 540 million litres per day of Cauvery water from the Torekadanahalli pump

Table 3.1: State-wise area in Cauvery Basin

State-wise area in Cauvery Basin					
State	**Karnataka**	**Kerala**	**Tamil Nadu**	**Pondicherry**	**Total**
Catchment area in sq. km of Cauvery Basin	34273	2866	43867	149	81155

station. The river served the livelihood of the ancient kingdom as well as modern cities in South India, as it has been supporting irrigated agriculture for centuries. The basin has 15 major hydroelectric projects and 24 power houses. Additionally, 96 dams, 10 barrages and 16 weirs have been constructed (EMPRI, 2017). The power plant built on the left of Shivanasamudram Falls on the Cauvery in 1902 was the first power plant in Asia. The Krishna Raja Sagara Dam has a capacity of 49 Tmc ft (thousand million cubic ft), and the Mettur Dam, which forms Stanley Reservoir, has a capacity of 93.4 Tmc ft.

3.2.2.1 Major crops

The land under cultivation in the basin is 48%. Around 24% of the cultivable area has some means of irrigation or other. There are mainly three crop seasons in the basin, viz. kharif, rabi and summer. The kharif crops are paddy, bajra, jowar, maize, ragi, cotton, millets, etc. Paddy is the most important crop in this basin, whereas ragi, jowar and other millets constitute the important crops under rainfed conditions. Major paddy-producing areas are eastern coastal or deltaic regions of Tamil Nadu, i.e., Thanjavur and Nagapattinam. Cuddalore and Pudukottai in Tamil Nadu and Mandya in Karnataka are also the areas where paddy cultivation is done at a large scale. While the central part of the basin has fewer areas covered by paddy, it has been observed that all the districts contribute to the paddy production in the area (Cauvery Basin, n.d.). Coconut, betel leaves, pepper, oranges, and lemon are grown as horticulture crops throughout the year. The main forest products are sandalwood, bamboo, teak, eucalyptus, blue gum, wattle, etc.

3.2.3 Pollution in Cauvery

Cauvery River is a good example of a site where contributions of pollutants both from natural (lithogenic) sources and anthropogenic activities. The river becomes polluted by the mixing of waste from industry, cultivated land, and municipal and household sewage, except pedogenic waste directly into the water (Mageshkumar et al., 2022). Analysis of water, plankton, fish, and sediment shows that the Cauvery River water downstream is polluted by certain heavy metals. Sediments accumulate at a rate of 0.4–4 mm/year. As depth increases, heavy metal concentration decreases. The heavy metal concentration at certain depths is recognised for the uneven input of metals and their remobilization (Ramanathan et al. 1996). A more recent study concluded that the waters of the Cauvery River are polluted by a range of emerging contaminants that include pharmaceutically active compounds, personal care products, plastics, flame retardants, heavy metals and pesticides, among many others (Down to Earth, 2021). CPCB water quality data reveals that 24.6% of the Cauvery River stretch in Karnataka has been polluted, particularly at Sri Rangapattina. Whereas the KSPCB water quality data reveals that the Cauvery River water quality falls in class C from 2004-2017 (Chidambaram et al., 2018). There seems to be a gap in the data at the state and central level.

3.2.4 Cauvery water dispute

The issue of water scarcity is estimated to have significant direct and indirect implications not only for the people living in society but is anticipated to have a much wider impact on economic growth and development. Statistically, it is argued that the issue of water scarcity has the tendency to lower the global GDP by almost 6% by 2050. Moreover, the impact of water scarcity is ascertained to be more severe for countries like India, which has a largely agriculture-based economy (Dolan et al., 2021)

The issue of water sharing became a national problem in India after the reorganisation of the states in 1956. The river Cauvery, originating in Kodagu district of Karnataka, flows through Tamil Nadu and a few regions of Kerala while reaching the Bay of Bengal. Considering Tamil Nadu's agricultural economy and past agreements, Karnataka is obliged to release water to them. Cauvery is a monsoonfed river line; scarce monsoon seasons push the Karnataka government to release less water, which in turn puts the Tamil government in great distress. The majority of the state earns from their large irrigation infrastructure, which becomes paralysed without water. This attained water is not even equitably distributed among the industries and farmers. As explained by Ramaswamy R. Iyer, water policy expert at the Centre for Policy Research, with a lack of judgement for disputes, dispute redressal only moves forward in terms of immediate need through judicial process and not a long-term structured process (Sharma, 2019).

The issue of Cauvery water sharing is aggravated by static allocation of water among co-basin states without considering the hydrological status of the co-basin states. The crux of a water-sharing problem lies in the determination of the equitable and reasonable share of water among the co-basin states in an objective manner considering all the relevant variables so that it could be acceptable to all the co-basin states, with the proposed model providing an answer to it (Garg & Azad, 2019).

3.3 Background of Urban and Industrial set up along the river

Tamil Nadu and Karnataka are the two most industrial states of India. Cities like Mysuru, Bengaluru, Erode, Coimbatore, Tiruppur, and Trichy support urban centres with growing economic activities. The Cauvery River, integral to the region, irrigates the fertile lands of Mysuru and Bengaluru as it flows through their industrial areas. However, as it enters the plains of Tamil Nadu, it faces pollution challenges, with pesticides and fertilisers entering the river. The most polluted stretches of the river are reported to be from Coimbatore to Tiruppur along the Bhavani River, downstream of Erode, and Thanjavur to Grand Anicut (CPCB, 2019). In Tamil Nadu, prominent industrial areas such as SIPCOT and TNSIDCO contribute to this pollution. The river's TDS (Total Dissolved Solids) measures 1,750 near Mettur and 1,450 near Erode, primarily due to garbage, effluents from textile industries, and tannery waste being discharged into the river (Deccan Herald, 2019).

3.3.1 Mapping of the Industrial Units (chemical) along the river

Hassan, a district with a diverse industrial landscape, hosts major industries in manufacturing, construction, and mining. It boasts 10 large and medium-scale industries with a total investment of INR 678 crore and a substantial 13,456 small-scale industries. Within the Cauvery basin, there are 6 major industrial areas and 7 major industrial estates. The prominent industries in this district include Textile, Food Processing, and Pharma (Department of Industries and Commerce, 2016)

Tumkur, on the other hand, contributes significantly to the region's economy, with a total GDP of INR 10,075 crore. The district accommodates 37 large and medium-scale industries and an impressive 27,322 small-scale industries. Key sectors in Tumkur encompass food processing, textile, steel, and cement mines, supported by 7 industrial estates and 7 industrial areas (Department of Industries and Commerce, 2016).

Moving to Mysuru District, it is graced by the presence of two major rivers, the Cauvery and Kabini. With a total of 7,515 MSMEs and 74 large and medium-scale industries scattered across 8 major industrial areas and 6 industrial estates, the district focuses on essential sectors like food processing and automobiles (Department of Industries and Commerce, 2016).

Bengaluru Rural District, an integral part of the Cauvery Basin, boasts 5 industrial areas and 2 industrial estates. Here, you will find prominent industries such as garments, automobile parts, electronic goods, and machine tools. Bengaluru

Urban, a hub within the Cauvery Basin, is recognised as one of the major industrial clusters in India. It is home to the largest biocluster in India, housing 137 biotechnology companies. Some of the notable MSME clusters include machine tools, leather products, and electronic goods (Department of Industries and Commerce, 2016)

Chamrajnagar, traversed by the River Palar, Suvarnavati, and Cauvery, accommodates 5 major medium-scale industries and 8,651 small-scale industries. The district comprises 3 major industrial estates, with agriculture being the primary economic activity, complemented by a smaller section engaged in manufacturing and mining (Department of Industries and Commerce, 2016)

Mandya, enriched by major rivers like Cauvery, Hemavathi, and Shimsha, focuses on industries such as solvent extraction, oil mills, textiles, and handlooms. The district houses 4 industrial areas and 5 industrial estates (Department of Industries and Commerce, 2016).

Ramnagar district is blessed with the presence of the River Arkavathi, a tributary of the Cauvery. With 64 large and medium-scale industries and 1,633 small-scale industries, the district emphasises sectors like chemicals, textiles, mechanical and automobile. It has 2 industrial areas and 4 industrial estates (Department of Industries and Commerce, 2016).

In Tamil Nadu Erode, Bhavani and Komarapalayam are home to approximately 600 leather tanneries, printing facilities, dyeing plants, and bleaching industries, all of which discharge untreated waste into the river and its tributaries (TNPCB, 2019). Mettur, in Salem, features thermal power stations, steel plants, cement factories, spinning mills, and oil bottling plants. Kumarpalayam in Nammakkal is renowned as the “Textile Town,” housing dyeing industries, spinning mills, and weaving units. Major contaminants near the Mettur dam in Salem include thermal power plants, chemical and pharmaceutical industries, and aluminium companies (TNPCB, 2019). In Erode, there are 468 consented textile bleaching and dyeing units, along with 37 consented

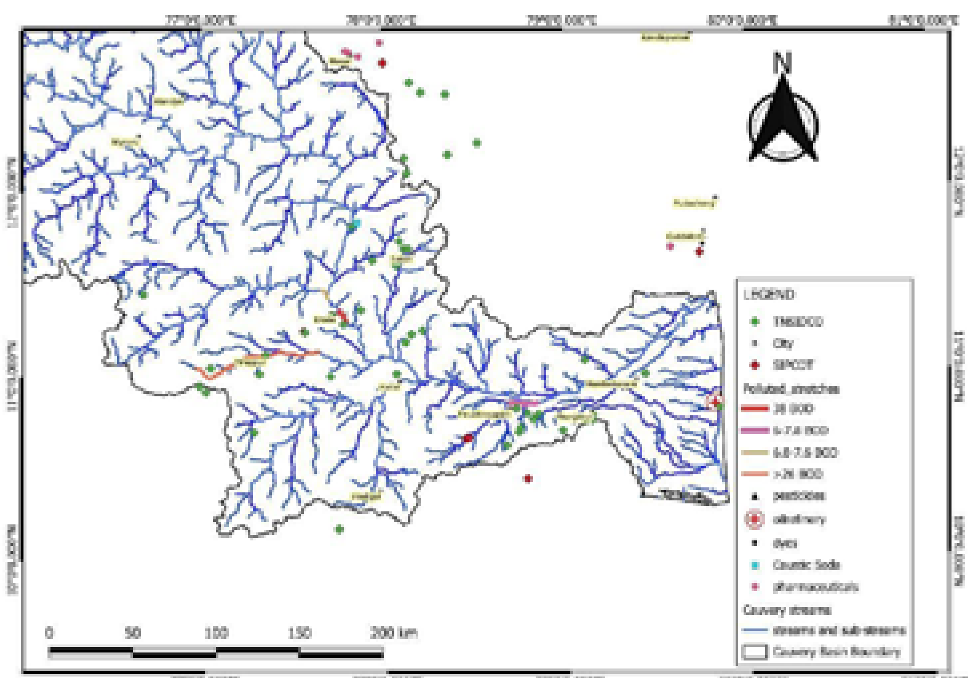

Figure 3.6: Major industrial areas in Cauvery Basin and polluted river stretches.

tannery units in proximity to the polluted river stretch (TNPCB, 2019). In Kumarapalayam, Nammakkal district, paper industries and 135 dyeing and bleaching industries are identified as highly polluting (TNPCB, 2019). Karur district, with rivers Noyyal and Amravathi as tributaries of the Cauvery, faces pollution issues due to dyeing effluent discharge from various dyeing and bleaching units located in Tirupur District. Trichy does not have direct industrial discharge into the river, but the presence of pesticides and fertilisers used in agriculture poses a potential threat. Thanjavur district reports no polluting industries discharging into the river, while Nagapattinam district hosts a few oil refineries.

3.3.2 Status of legacy POPs and new POPs along the river basin.

A gas chromatograph-mass spectrometer (GC-MS) was used to analyse organochlorine pesticides (OCPs) in the muscle tissues of five fish species (*O. mossambicus, L. parsia, E. suretensis, C. striata,* and *S. wynaadensis*) from seven locations in the River Cauvery by Bhuvaneshwari and Rajendran (2012). The study detected OCPs such as DDTs, HCHs, CHLs, cyclodienes, heptachlor, HCB, and mirex with varying concentrations among species and locations. Fish species with higher concentrations of aldrin, dieldrin, and mirex showed significant carcinogenic risk to human consumers. A comprehensive assessment was conducted to examine OCPs in the surface water samples of the Cauvery River (Patil et al., 2015). The study revealed the presence of various OCPs, including HCHs, DDTs, endosulfan, aldrin, dieldrin, heptachlor epoxide, and others. Concentrations of HCHs, DDTs, and endosulfan in the river water were measured at levels of up to 2,300 ng/L, 3,600 ng/L, and 15,400 ng/L, respectively. In sediment samples, HCHs and DDTs were found with maximum concentrations of 158 ng/g dw and 9.15 ng/g dw, respectively. Furthermore, biota samples (fish, shrimp) collected from the river showed significant levels of HCHs (228 ng/g) and DDTs (2,805 ng/g). Alarmingly, certain OCP levels in the Kaveri River exceeded safety guideline values, indicating potential threats to resident organisms due to ongoing exposure (Patil et al., 2015).

A recent study focused on the impact of land use, streamflow, and seasonal variations on pesticide concentrations in surface water runoff entering the Cauvery River in Karnataka state (Latha and Mohan, 2019). Samples were collected from various stations throughout the year 2015. The pesticides most detected in this research are frequently used in developed areas, especially on paddy, sugarcane, and ragi crops. The combined concentrations of organochlorine pesticides (DDT, DDE, and DDD), organophosphates (malathion, diazinon, and chlorpyrifos), and carbamates (carbaryl) were found to be higher during the pre-monsoon season compared to the post-monsoon season. Notably, all quantified pesticides showed a significant decrease in concentration during the post-monsoon period. Air samples taken from the vicinity of the Cauvery River in Tamil Nadu, southern India (Srimurali et al., 2015) were analysed to assess the distribution and persistence of OCPs. Passive air sampling was conducted in urban, suburban, coastal, and agricultural areas between April 2009 and January 2010. Polyurethane foam samples were exposed for around 30 days and then subjected to soxhlet extraction. The extracted samples were subsequently analysed using gas chromatography-mass spectrometry. The total concentrations of 13 OCPs ranged from not detected (ND) to 41,400 pg/m^3. During the monsoon season, certain OCPs like DDT, DDE, heptachlor, and mirex were found to be predominant. Interestingly, a high a/c isomer ratio of hexachlorocyclohexane (HCH) (5.03) during the summer indicated recent usage of HCH in the coastal area. A study conducted in Karnataka, India, focused on OCPs in fish from the Cauvery River stretch (Dhananjayan and Muralidharan, 2010) within inland wetlands. Among the tested OCPs, HCH isomers, specifically β-HCH and γ-HCH, were the most frequently detected, serving as the primary pollutants. The average concentration of HCH ranged from 2.1 to 51.7 μg/kg, while DDT was found below the detection level to 12.3 μg/kg. Analysing various fish species, it was observed that *Anguilla bicolor* had the highest pesticide burden (77.9 μg/kg), while *Heteropneustes fossilis* exhibited the lowest pesticide levels (2.1 μg/kg). Rajendran and Subramanian (1997) conducted an observation of ΣHCH and ΣDDT concentrations in the Cauvery estuaries. They found concentrations ranging from 3.2 to 182.0 ng/l for ΣHCH and from 0.8 to 4.2 ng/l for ΣDDT. Among the isomers of HCH, they noted a predominance of α-HCH.

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Chapter 4
REGULATORY FRAMEWORK, POLICIES AND PROGRAMMES IN POPS MANAGEMENT

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4.1 International Regulatory Frameworks, Policies, and Programmes for POPs management

Key Global Governance Initiatives for POPs management

Convention on Long-Range Transboundary Air Pollution (CLRTAP), 1979

The 1979 Convention on Long-Range Transboundary Air Pollution (LRTAP), the first multilateral agreement addressing transboundary air pollution, created a regional framework applicable to Europe, North America and Russia and former East Bloc countries for reducing transboundary air pollution and better understanding of the air pollution science. The 1979 CLRTAP addressed the key environmental problems of the UN Economic Commission for Europe (UNECE) region through scientific collaboration and policy negotiations. The Convention has been extended by eight protocols that identify specific measures to be taken by Parties to cut their emissions of air pollutants. The Protocol to the Convention on Long-Range Transboundary Air Pollution on Persistent Organic Pollutants ("LRTAP POPS Protocol") was opened for signature at the UNECE ministerial meeting in Aarhus, Denmark from 23-25 June 1998.

Aarhus Protocol on POPs, 1998

The Aarhus Protocol on POPs was adopted in 1998 and has been applicable since 2003. This global treaty prohibits the production and use of a certain number of POPs in Europe, North America, and Central Asia. The Protocol by the UNECE considered the proper disposal of waste products deemed banned and limited, including medical supplies. A total of 16 POPs were targeted by this protocol comprising eleven pesticides, two industrial chemicals and three by-products/contaminants, as follows:

- *Originally added:* aldrin, chlordane, kepone, DDT, dieldrin, PCDDs (polychlorinated dibenzo-p-dioxins), PCDFs (polychlorinated dibenzofurans), endrin, PAHs (polycyclic aromatic hydrocarbons),
- *Recognised:* lindane (HCH), heptachlor, hexabromobiphenyl, hexachlorobenzene, mirex, PCBs, and toxaphene.

Stockholm Convention, 2001

The Stockholm Convention on Persistent Organic Pollutants is an international environmental treaty, signed on 22 May 2001 in Stockholm (Sweden) and effective from 17 May 2004, that aims to eliminate or restrict the production and use of POPs. India had ratified the Stockholm Convention on January 13, 2006, as per Article 25(4), which enabled it to keep itself in a default "opt-out" position such that amendments in various Annexes of the convention cannot be enforced on it unless an instrument of ratification/ acceptance/approval or accession is explicitly deposited with the UN depositary. The POPs banned by the SC from time to time are given in **Table 4.1**. Countries are proposing to list new chemicals (or **candidate POPs**) in Annex A, B, or C of the SC. In May 2023, Dechlorane Plus (flame retardants),

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Table 4.1: POPs banned by the Stockholm Convention

Sl. No.	Chemical	Year of listing	Annex	Exemptions for Use
1	Aldrin	2001	A: Elimination	none
2	Chlordane	2001	A: Elimination	none
3	Chlordane	2001	A: Elimination	none
4	DDT	2001	B: Restriction*	Disease vector control *
5	Dieldrin	2001	A: Elimination	None
6	Endrin	2001	A: Elimination	None
7	Heptachlor	2001	A: Elimination	None
8	Hexachlorobenzene	2001	A: Elimination C: Unintentional production	None
9	Mirex	2001	A: Elimination	None
10	Polychlorinated biphenyls (PCBs)	2001	A: Elimination C: Unintentional production	None
11	Polychlorinated dibenzodioxins and dibenzofurans (PCDD/PCDF)	2001	C: Unintentional production	–
12	Toxaphene	2001	A: Elimination	None
13	α-Hexachlorocyclohexane	2009	A: Elimination	None
14	β-Hexachlorocyclohexane	2009	A: Elimination	None
15	Chlordecone	2009	A: Elimination	None
16	β-Hexachlorocyclohexane	2009	A: Elimination	None
17	Chlordecone	2009	A: Elimination	None
18	Hexabromobiphenyl	2009	A: Elimination	None
19	Hexabromodiphenyl ether and heptabromodiphenyl ether	2009	A: Elimination	Recycling under certain conditions
20	Lindane	2009	A: Elimination	Human health pharmaceutical for control of head lice and scabies as second line treatment
21	Pentachlorobenzene	2009	A: Elimination C: Unintentional production	None

Sl. No.	Chemical	Year of listing	Annex	Exemptions for Use
22	PFOS, its salts and perfluorooctane sulfonyl fluoride	2009	B: Restriction*	Hard metal plating, insect baits for control of leaf-cutting ants, fire-fighting foams *
23	Tetrabromodiphenyl ether and pentabromodiphenyl ether	2009	A: Elimination	Recycling under certain conditions
24	Endosulfan	2011	A: Elimination #	Crop-pest complexes #
25	Hexabromocyclododecane	2013	A: Elimination #	Expanded polystyrene and extruded polystyrene in buildings #
26	Hexachlorobutadiene	2015	A: Elimination C: Unintentional production	None
27	Pentachlorophenol and its salts and esters	2015	A: Elimination *	Utility poles and cross-arms *
28	Polychlorinated naphthalenes	2015	A: Elimination * C: Unintentional production	Production of polyfluorinated naphthalenes, including octafluoronaphthalene *
29	Decabromodiphenyl ether	2017	A: Elimination #	Vehicles, aircraft, textile, additives in plastic housings etc., polyurethane foam for building insulation #
30	Short-chain chlorinated paraffins (C10–13; chlorine content > 48%)	2017	A: Elimination *	Additives in transmission belts, rubber conveyor belts, leather, lubricant additives, tubes for outdoor decoration bulbs, paints, adhesives, metal processing, plasticizers*
31	Dicofol	2019	A: Elimination	None
32	PFOA, its salts and PFOA-related compounds	2019	A: Elimination *	Various *
33	Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds	2022	A: Elimination	None

*Exemptions for production: * Production for the specified uses; # As allowed for the parties listed in the Register*

Table 4.2: List of proposed (candidate) POPs under the Stockholm Convention

Candidate POPs	Uses
Chlorpyrifos	Insecticide in agriculture and biocide for non-agricultural pests; also, public health uses (adulticidal fogger treatments for mosquitoes, control of fire ants)
Chlorinated paraffins with carbon chain lengths in the range C_{14-17} and chlorination levels at or exceeding 45% chlorine by weight	Used as a secondary plasticizer; a flame retardant in PVC and rubber compounds, adhesives, sealants, paints and coatings, and textiles; an extreme pressure lubricant and anti-adhesive for metal working fluids; a waterproofing agent for paints, coatings and textiles; and a carrier solvent for colour formers in paper manufacture.
Long-chain perfluorocarboxylic acids (PFCAs), their salts and related compounds	Surfactant applications and production of fluoropolymers; also in coating products, fabric/ carpet protectors, textile impregnation agents and firefighting foams.
Octamethylcyclotetrasiloxane (D4); Decamethylcyclopentasiloxane (D5); Dodecamethylcyclohexasiloxane (D6)	Restrictions on putting in wash-off cosmetic products (sold in markets) in a concentration equal to or greater than 0.1 % by weight of either substance, after 31 January 2020. "Wash-off cosmetic products" refers to cosmetic products (under Article 2 (1) (a) of Regulation (EC) No 1223/2009) that are washed off with water after application, under normal conditions of use.

ultraviolet stabilizer UV-328 as well as the pesticide methoxychlor were restricted under the Convention.

The POPs Review Committee will evaluate the proposals and make recommendations to the Conference of the Parties on such listing as per Article 8 of the Convention. The list of proposed POPs under the SC and their uses are given in **Table 4.2**.

Rotterdam Convention, 1998 (signed)

The 'Rotterdam Convention on the Prior Informed Consent (PIC) Procedure for Certain Hazardous Chemicals and Pesticides in International Trade' is a multilateral treaty to promote shared responsibilities in relation to importation of hazardous chemicals. The PIC procedure applies to all the chemicals listed in Annex III of the Convention. The Convention promotes open exchange of information and promotes proper labeling of hazardous chemicals to inform purchasers of legal restrictions. There are a total of 54 chemicals listed in Annex III, 35 pesticides (including three severely hazardous pesticide formulations), 18 industrial chemicals, and one chemical in both the pesticide and the industrial chemical categories. The list of chemicals including POPs under the Rotterdam Convention (Annex III) is given in **Table 4.3**.

Basel Convention and Basel Ban Amendment, 1989 (signed)

The Basel Convention on the 'Control of Transboundary Movements of Hazardous Wastes and Their Disposal' is an international treaty to reduce the movements of hazardous waste between nations, and specifically to prevent transfer of hazardous waste from developed to less developed countries. The Convention was opened for signature on 21 March 1989, and entered into force on 5 May 1992. As of June 2023, there are 191 parties to the convention.

The Basel Convention and the Stockholm Convention (SC) have a joint mandate on establishing levels of destruction and control and/or reduce POPs. Also, the Conferences of the Parties of the two Conventions determine cooperatively what methods should constitute environmentally sound disposal. The Basel Convention has developed technical guidelines

Table 4.3: List of chemicals (including POPs) under Rotterdam Convention (Annex III)

Sl. No.	Chemical
Pesticide	
1	2,4,5-T and its salts and esters
2	Alachlor
3	Aldicarb
4	Aldrin
5	Azinphos-methyl
6	Binapacryl
7	Captafol
8	Carbofuran
9	Chlordane
10	Chlordimeform
11	Chlorobenzilate
12	DDT
13	Dieldrin
14	Dinitro-ortho-cresol (DNOC) and its salts
15	Dinoseb and its salts and esters
16	EDB (1,2-dibromoethane)
17	Endosulfan
18	Ethylene dichloride
19	Ethylene oxide
20	Fluoroacetamide
21	HCH (mixed isomers)
22	Heptachlor
23	Hexachlorobenzene
24	Lindane (gamma-HCH)
25	Mercury compounds
26	Methamidophos
27	Monocrotophos
28	Parathion

Sl. No.	Chemical
29	Pentachlorophenol and its salts and esters
30	Phorate
31	Toxaphene (Camphechlor)
32	Tributyl tin compounds
33	Trichlorfon
Pesticide Formulation	
1	Dustable powder formulations containing a combination of benomyl, carbofuran and thiram
2	Methyl-parathion
3	Phosphamidon
Industrial	
1	Actinolite asbestos
2	Amosite asbestos
3	Anthophyllite asbestos
4	Commercial octabromodiphenyl ether
5	Commercial pentabromodiphenyl ether
6	Crocidolite asbestos
7	Decabromodiphenyl ether (decaBDE)
8	Hexabromocyclododecane
9	Perfluorooctane sulfonic acid, perfluorooctane sulfonates, perfluorooctane sulfonamides and perfluorooctane sulfonyls
10	Perfluorooctanoic acid (PFOA), its salts
11	Polybrominated Biphenyls (PBBs)
12	Polychlorinated Biphenyls (PCBs)
13	Polychlorinated Terphenyls (PCTs)
14	Short-chain chlorinated paraffins (SCCP)
15	Tetraethyl lead
16	Tetramethyl lead
17	Tremolite asbestos
18	Tributyltin compounds
19	Tris(2,3-dibromopropyl) phosphate

on the Environmentally Sound Management of POPs wastes. Parties to the SC are invited to take these guidelines into account when implementing their obligations under Article 6 of the Convention. Technical guidelines provide for the foundation upon which countries can operate at a standard that is not less environmentally sound than that required by the Basel Convention. The Convention covers hazardous wastes that are explosive, flammable, poisonous, infectious, corrosive, toxic, or ecotoxic. The categories of wastes and the hazardous characteristics are set out in Annexes I to III of the Convention. Lists of specific wastes characterized as hazardous or non-hazardous are in Annexes VIII and IX. POPs wastes are listed as wastes in Annexes I and VIII of the Basel Convention text.

Other International Governance Initiatives for POPs management

Arctic Contaminants Action Programme (ACAP), 2001

The original Arctic Council Action Plan to Eliminate Pollution of the Arctic, now known as the Arctic Contaminants Action Programme (ACAP), was adopted at the SAO (Senior Arctic Officials) Meeting in 2001 and provided the first mandate for work on POPs and mercury. The initial work of ACAP focused on PCBs, dioxins and furans, mercury, obsolete pesticides and cleaner production. ACAP was established in 2006. The POPs & Mercury expert group projects were aimed at contributing to implementation of the SC, the POPs and Heavy Metals Protocols of the UN/ ECE CLRTAP, the Minamata convention, etc. POPs and mercury are priority pollutants in the Arctic region and in ACAP's Strategy to Address Contamination of the Arctic Environment and its People for 2016-2020 (Artic Council, N.d.).

Strategic Approach to International Chemicals Management (SAICM), 2006

In February 2006, in Dubai (United Arab Emirates), the Strategic Approach to International Chemicals Management (SAICM) was adopted as a global policy framework to promote chemical safety. SAICM was developed as a voluntary approach and supported the achievement of the goal agreed at the 2002 Johannesburg World Summit on Sustainable Development, by the year 2020. The overall objective was the achievement of sound management of chemicals throughout their life cycle so that chemicals were produced and used in ways that would minimize negative impacts on human health and the environment. SAICM comprised the Dubai Declaration on International Chemicals Management (towards political commitment to SAICM), and an Overarching Policy Strategy (setting out its scope, needs, objectives, financial considerations, etc.). The objectives of SAICM were grouped under five themes of risk reduction; knowledge and Information; governance; capacity-building and technical cooperation; and illegal international traffic.

International Panel on Chemical Pollution (IPCP)

Established in 2008, the IPCP seeks to gather scientific data on chemical pollution at the national and international levels, utilizing the most recent scientific findings. It then disseminates and interprets this data to the public and decision makers. Pesticides and biocides, pharmaceuticals, industrial chemicals including flame retardants, solvents, and plastic softeners, as well as undesirable byproducts like polychlorinated dibenzodioxins and furans, are some of the main chemical categories covered by IPCP. The IPCP helps national and international political processes, particularly in relation to the SC, based on its scientific competence.

International Knowledge Hub Against Plastic Pollution (IKHAPP)

The SC banned two plastic additives - UV-328 and Dechlorane Plus (a chlorinated flame retardant), in 2023. In connection to these two POPs, it is crucial to highlight IKHAPP, an International Knowledge Hub Against Plastic Pollution. Initiated in 2021, IKHAPP is driven by a global network of scientists that seek to comprehend the causes, effects, and determinants of plastic pollution as well as the efficacy of various mitigation strategies. IKHAPP's goal is to gather, evaluate, and share scientific knowledge to promote worldwide policies and initiatives that effectively combat plastic pollution. IKHAPP is a part of ASAP – Asian Scientific Alliance for Plastic Pollution and Value Network Management, a project supported by The Research Council of Norway.

International Pollutants Elimination Network (IPEN)

Previously known as the International POPs Elimination Network comprising a global network of over 550 public-interest non-governmental organizations (NGOs), the International Pollutants Elimination Network (IPEN) is committed to pollution control of lead in paint, mercury and lead in the environment, POPs, endocrine disrupting substances, and other toxic chemicals. IPEN is made up of non-governmental groups that serve the public interest and promote the Stockholm Convention's goal of eliminating POPs globally. IPEN also works to influence the implementation of the Rotterdam and Basel agreements and the Minamata Convention on Mercury. Spread over 120 countries, IPEN collaborate to eliminate these harmful chemical pollutants quickly but fairly and aims to create a world wherein POPs and chemicals will be manufactured and utilized in ways that minimize their severe negative impacts on human health and the environment.

Intergovernmental Forum on Chemical Safety (IFCS)

The Intergovernmental Forum on Chemical Safety (IFCS) was an alliance of stakeholders concerned with the sound management of chemicals. It operated based on full and open participation of all partners, serving as a facilitator and advocate for bringing order to global actions taken for chemical safety. The idea of an intergovernmental forum to address chemical safety originated during preparations for the 1992 United Nations Conference on Environment and Development (Earth Summit) and was called for in Chapter 19 of Agenda 21, the programme of action adopted by the conference. After the adoption of the Strategic Approach to International Chemicals Management (SAICM) by the International Conference on Chemicals Management (ICCM) in February 2006, the Forum was forced to consider its future role. The sixth meeting of the IFCS in 2008 proposed its integration with SAICM as an advisory body. However, in 2009, the ICCM rejected this proposal and the IFCS has been dormant since (IISD, n.d.).

Other EU Regulations on POPs management

The RoHS Directive, POPs Regulation (Regulation (EU) 2019/1021) and REACH Regulation (Regulation (EC) 1907/2006) share the key objectives, namely the protection of human health, and the environment. All three pieces of legislation employ similar mechanisms, the restriction of the use of hazardous substances, to achieve these goals. The POPs Regulation restricts a greater range of substances than the RoHS Directive (which also controls some POPs). The Regulation is enforced at individual substances, mixture and article level. It defines an article is defined as an object, which during production is given a special shape, surface or design which determines its function to a greater degree than does its chemical composition. Also, the POPs Regulation requires waste containing specified levels of POPs to be treated so the POPs are destroyed and aims to limit releases of unintentionally produced POPs into the environment.

POPs Regulation (Regulation (EU) 2019/1021)

Although the SC decides POPs and implementation obligations globally, the European Union (EU) has its own POPs legislation that was developed and enacted in accordance with the requirements. The EU prohibits or places restrictions on the manufacturing and/or use of POPs under Regulation (EU) 2019/1021. The regulation is designed to protect both human health and the environment through the following approaches:

- Prohibit the manufacturing, marketing, and usage of POPs.
- Minimize environmental emission of POPs byproducts.
- Ensure that restricted POP stockpiles are managed safely.
- Examine how POPs waste or waste contaminated by POPs is disposed of.

REACH Regulation (Regulation (EC) 1907/2006)

REACH is the Regulation for Registration, Evaluation, Authorisation and Restriction of Chemicals. It entered into force on 01 June 2007 to streamline and improve the former legislative framework on chemicals in the EU. The REACH Regulation (Regulation (EC) 1907/2006), covers virtually all substances (hazardous and non-hazardous) manufactured, imported, and used within the EU. The REACH Regulation does not regulate wastes.

RoHS Directive

The Restriction on the use of certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) Directive specifically restricts the use of hazardous substances in electrical and electronic equipment (EEE) and so promotes its recycling. While the Directive's compliance is evaluated at the homogenous material and individual component level, the Directive is enforced at the product level. The scope of the Directive is limited to certain EEE and to a limited number of specified substances. The substances restricted under the Directive include lead, chromium VI, mercury, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE), phthalates - bis(2-ethylhexyl) phthalate (DEHP), benzyl butyl phthalate (BBP), dibutyl phthalate (DBP), and diisobutyl phthalate (DIBP).

4.1.1 National Government regulatory Initiatives for POPs management

The SC is among the most important guiding laws in regulating POPs at the global level. As of September 2022, there are 186 members (185 countries and the EU) in the Convention. The non-ratifying countries include the United States, Israel, and Malaysia. All participating nations developed their own national implementation plans (NIPs) to prevent or minimize POP releases from both purposeful and inadvertent manufacturing to implement the SC. In Europe, North America, and many South American nations, the use of all POPs listed in the SC list has been banned. There are certain regional regulations with a smaller jurisdiction size such as REACH, EU regulation for the Placing of Plant Protection Products on the Market (EC 1107/2009), the United Nations Economic Commission for Europe (UNECE) POPs Protocol and the North American Sound Management of Chemicals. There are also certain national laws in existence, such as the chemical management plan mandated by the Toxic Substances Control Act in the United States (1976) or the Canadian Environmental Protection Act (1999). Other national laws and regulations exist in nations like Australia, China and India. POP levels have decreased over time as a result of these regional, national, and worldwide regulation initiatives. Due to their weak economies, many countries (Botswana, Eritrea, Eswatini, Ethiopia, India, Mauritius, Micronesia and others) continue to use some banned POPs in agriculture and public health purposes, which is permitted under the SC because the benefits to public health outweigh any potential risks.

The international regulatory frameworks, policies, and programmes are crucial for addressing the global and transboundary nature of POPs pollution, and for protecting human health and the environment. Countries around the world also collaborate through different ways to reduce POPs emissions, regulate their use, and safely manage POPs-containing waste. Some regions, such as the EU, have developed their own regulations and programmes to manage POPs. For example, the EU has its POPs Regulation, which aligns with the SC but may include additional restrictions on POPs: the EU Regulation 2019/1021 since July 2019, and the

EU Amending Regulation 2022/2400 has applied since June 2023. Also, various international and national organizations, including the United Nations Environment Programme (UNEP), the World Health Organization (WHO), and the U.S. Environmental Protection Agency (EPA), conduct research and monitoring programmes to assess the presence and impacts of POPs in the environment and human health. Also, international organizations, such as the UNEP and the Global Environment Facility (GEF), provide technical assistance and capacity-building programmes to help countries develop the necessary infrastructure and expertise to manage POPs and toxic chemicals effectively.

4.2 Documentation of Global Management of POPs

The Countries that are Parties to the Stockholm Convention (SC) are obligated to prohibit or restrict the production, use, and trade of POPs listed in Annex A and Annex B of the Convention. Parties to the Convention are also bound to reduce or eliminate unintentionally produced POPs listed in Annex C. For this purpose, Article 7 of the Convention requires all Parties to develop a plan for the implementation of their obligations, known as their National Implementation Plan (NIP). The NIP outlines proposed actions to manage POPs under the SC, which have been ratified by the Party. Furthermore, the Article also requires Parties to "review and update" the NIP periodically, incorporating new POPs added to the list. The NIP serves as a foundation for Parties to eliminate the POPs and promulgating regulations to manage and phase out POPs in due course.

EU regulations on POPs

The EU countries were among the first to recognise the dangers posed by POPs. Concerns about the toxicity, persistence, and long-range transport potential of certain chemicals, including polychlorinated biphenyls (PCBs) and DDT, started gaining attention in the 1970s and 1980s. Subsequently, the EU has been a proponent for regulating POPs, leading to the following developments:

- On 30th April 2004, the EU introduced the Directive 2004/35/EC (on environmental liability regarding the prevention and remedying of environmental damage) way before the SC came into force. These directives established a framework for environmental liability to prevent and remediate damage caused by activities involving POPs and other hazardous substances (Directive 2004/35/CE) (European Union, 2004a).
- On 16 November 2004, the EU ratified the SC and, in the same year, adopted a new regulation (EU Regulation (EC) No. 850/2004) to implement the Convention within the EU. The regulation laid out comprehensive measures aimed at controlling the production, usage, release, and disposal of POPs. Additionally, it established a list of priority substances that were subject to restrictions, along with stipulating requirements for their elimination or reduction (European Union, 2004b).
- The EU's Regulation (EC) No. 1907/2006, known as the REACH (Registration, Evaluation, Authorization, and Restriction of Chemicals) Regulation, entered into force in 2007. While it is not exclusively focused on POPs, REACH mandates the registration and evaluation of chemicals, including those classified as persistent and toxic (European Union, n.d.).
- Implementation Plans were developed in 2007, 2014, and 2019, to meet the EU's commitments under the SC. (The implementation plans have been extensively discussed in the INOPOL Baseline Report 2021). Currently, a fourth implementation plan is under development.
- In 2019, the EU updated its regulation on POPs by adopting Regulation (EU) No. 2019/1021, which strengthened the EU's efforts to implement the SC and the Protocol to the 1979 Convention on Long-range Transboundary Air Pollutants on POPs ('the Protocol') (European Union, 2019).

Under the 2019 Regulation, definitions of terms like 'substances', 'mixtures', 'articles' and 'unintentional trace contaminant' are better clarified and aligned with the REACH Regulation and Waste Framework Directive 2008/98/EC. The Regulation has also streamlined chemical management in the EU by making the European Chemicals Agency (ECHA) responsible for carrying out the administrative, technical, and scientific aspects of POPs regulation. Overall, the Regulation aims to protect human health through specific control measures that:

- Prohibit or restrict the production, marketing, and use of POPs
- Minimize environmental release of POPs by-products
- Ensure the safe management of restricted POPs stockpiles
- Monitor the proper disposal of POPs waste or waste contaminated by POPs

The Regulation has seven annexes, five of which list substances that are covered by specific provisions. The first two annexes list chemicals that are included in the SC and the Protocol, or one of them. Annex III lists substances that are subject to release reduction provisions; and finally, Annex IV and V deal with waste management provisions. Waste containing or contaminated by any substance listed in Annex IV may be otherwise disposed of or recovered in accordance with the relevant Union legislation, provided that the content of the listed substances in the waste is below the concentration limits specified in Annex IV.

Since 2019, the Regulation has been amended several times to add new chemicals to the annexes and to add or repeal specific exemptions under which some of the listed chemicals can be produced/used. PFOA, its salts and PFOA-related compounds (Commission Delegated Regulation (EU) 2020/784) (European Union, 2020a), and dicofol (Commission Delegated Regulation (EU) 2020/1024) (European Union, 2020b) were added to Annex I in this manner.

In October 2022, the European Commission published Regulation (EU) 2022/2002, amending Annexes of Regulation (EC) No 1881/2006 regarding maximum levels for dioxins and dioxin-like polychlorinated biphenyls (PCBs) in certain foodstuffs (European Union, 2022a). This was based on a new scientific opinion on the risks to animal and public health related to the presence of dioxins and dioxin-like PCBs in feed and food, adopted by the European Food Safety Authority (ESFA) in 2018. This new Regulation came into effect in January 2023.

In December 2022, the EU introduced a new Regulation on POPs in waste (Regulation (EU) 2022/2400). Through this regulation, the existing concentration limits of POPs in waste were tightened and new limits have been introduced for four new POPs (pentachlorophenol, dicofol, PFOA and PFHxS) (European Union, 2022b). Limiting the presence of these chemicals in waste will boost the supply of safe, toxic-free secondary raw materials and prevent POPs from re-entering the circular economy.

Development of REACH regulation to manage POPs

REACH is a EU regulation, introduced for prompt and better identification of chemicals that may pose a risk to human health and the environment so that these risks can be managed. It is a comprehensive regulation that applies to all chemical substances, from intermediate goods used in industries to final goods used by consumers in their daily lives. Therefore, the regulation has an impact on companies across different sectors in the EU. The comprehensive and uniform system for the regulation, evaluation and restriction of chemicals can help manage chemical hazards, including those from POPs.

REACH specifies methods by which companies can gather data on the properties and hazards of chemicals to register them. By requiring them to identify and manage the risks linked to the substances they manufacture and market in the EU, REACH puts the burden of proof on the companies. Individual registrations are received and evaluated by the ECHA for compliance with the EU regulations, and EU Member States review selected compounds to articulate their concerns for human health or the environment. Authorities and ECHA's scientific committees analyse whether these chemical hazards can be managed. REACH has three major lists under which chemicals are enumerated for regulation, restriction, and authorisation:

a) REACH SVHC (Substances of Very High Concern)

Listing a substance as an SVHC is the first step in the procedure for authorisation or restriction of use of a chemical. The list contains all substances that are:

- Persistent, bio-accumulative, and toxic (PBT) substances, or
- Very persistent and very bio-accumulative (vPvB), or
- Very persistent and very mobile (vPvM)
- Known to meet the criteria for classification as carcinogenic, mutagenic or reprotoxic (CMR) category 1 or 2
- Known to pose similar concerns, such as endocrine disruptors.

The first list of SVHCs was published on 28 October 2008 and the list has been updated many times to include new candidates. In 2023, ECHA added 11 substances to the list. The most recent update occurred in June 2023, taking the total to 235 SVHC (European Chemicals Agency [ECHA], n.d.(a).The inclusion in the Candidate List brings immediate obligations for suppliers of the substance, such as:

- Supplying a safety data sheet
- Communicating on safe use
- Responding to consumer requests within 45 days and
- Notifying ECHA if the article they produce contains an SVHC in quantities above one tonne per producer/importer per year and if the substance is present in those articles above a concentration of 0.1% (w/w).

b) REACH Authorisation list (Annex XIV)

The authorisation process aims to ensure that substances of very high concern (SVHCs) are progressively replaced by less dangerous substances or technologies where technically and economically feasible alternatives are available. Substances in Annex XIV are chosen from the SVHC list and cannot be used or placed on the market after a sunset date specified in the Annex, unless an authorisation is obtained for their specific use, or the use is exempted from authorisation within the Annex. There are presently 59 substances on the list; 49 of these are already past their sunset date (European Chemicals Agency [ECHA], n.d.(b).

c) REACH Restricted Substances List

Annex XVII of the REACH regulation includes a list of restrictions on the marketing and use of certain hazardous chemicals, mixtures, and articles in the European market. Any substance, whether alone, in a mixture, or in an article, can be subject to a limitation, including those that do not need registration. The list currently includes 76 substances (European Chemicals Agency, n.d.(c).

When hazardous POPs need to be restricted further, or banned, they can be added to the Annexes of the POP Regulation discussed before. For example, PFOS was originally included in the REACH Restricted Substances list (Annex XVII). Once PFOS was added to Annex B of the SC, the European Commission transferred it to Annex I of the EU POPS regulation (Regulation (EC) No 850/2004) (European Union, 2004b).

POPs Management in the United States (US)

The US signed the SC in May 2001. However, the Convention was never ratified by the US Senate. Despite this, the US has taken independent efforts in the management of hazardous materials that includes POPs as well:

- The US and Canada signed an **agreement for the Virtual Elimination of Persistent Toxic Substances in the Great Lakes** to reduce emissions from toxic substances. In addition, extensive fish contaminant monitoring programmes and fish consumption advisories are regularly released in the Great Lakes states to help inform people.
- The US has signed the regional protocol of the United Nations Economic Commission for Europe on POPs under the **Convention on Long-Range Transboundary Air Pollution** (Geneva Convention). The original agreement addressed the 12 SC POPs and 4 additional chemicals (hexachlorocyclohexanes, hexabromobiphenyl,

chlordecone, and polycyclic aromatic hydrocarbons), and includes a mechanism for adding additional substances to the agreement.

- **PCBs:** The US has some regulation in place under TSCA since 1970s though initially it was majorly focused on disposal of PCBs containing wastes but in 1979 under 44 FR 31514 Toxics Substance Control Act (TSCA) manufacturing, processing, distribution in commerce and use of PCBs got banned with some exceptions (U.S. Environmental Protection Agency, 2024). Since then, several amendments, rules and policies have been introduced to control manufacturing and usages of PCBs in different sectors (Connecticut Department of Energy and Environmental Protection, 2016).
- **Stopping DDT use:** In 1970, the US Department of Agriculture banned DDT applications on crops, commercial plants, and wood products, as well as for building purposes. In 1972, the registrations of the remaining DDT products were cancelled. By 1989, the remaining exempted uses (including the public health use for controlling vector-borne diseases) were voluntarily stopped. As a result of these decisive actions, the bald eagle, which is particularly susceptible to a metabolite of DDT, has experienced a very dramatic species recovery.
- **Dioxins and Furans:** The US Environmental Protection Agency has attempted to manage the release of dioxins and furans to air, water and soil. Major sources of these toxic POPS, regulated under the agency include municipal, medical, and hazardous waste incineration; pulp and paper manufacturing; and certain metals production and refining processes.

POPs Management in Developing Countries

China

China signed the SC in May 2001 and ratified it in June 2004 with an opt-in clause as per the need and requirement. In April 2007, the country issued its NIP for the SC on POPs, outlining objectives and measures for the Convention's implementation. The NIP set goals in stages, both by region and industry, specifically targeting the initial group of 12 POPs listed in the Convention (NIP China, N.d.). These goals included the prohibition and prevention of the production and import of certain POPs (aldrin, dieldrin, endrin, heptachlor, HCB, toxaphene and PCBs), while simultaneously working towards eliminating the production, use, import, and export of others (chlordane, mirex and DDT). Furthermore, the plan sought to achieve the implementation of Best Available Techniques and Best Environmental Practices (BAT/BEP), as well as the environmentally sound management POPs wastes within specific deadlines.

As of December 2017, the number of restricted and controlled POPs in the country had increased from 12 to 23. It is important to note that the ratification of HBCD was only applicable to the Special Administrative Regions of Hong Kong and Macao. China submitted its second NIP in 2018. This revised NIP outlined major objectives, which included the prohibition of production, use, import, and export of specific POPs, such as lindane, endosulfan, PFOS, and PFOS-F, all within specific timeframes (COP 6 Amendments, China. n.d.). By December 2021 China has ended the production, use, import and export of hexabromocyclododecane (HBCD) (Arthur, 2022). On June 6, 2023, the Chinese government issued an announcement to adopt proposed provisions for the elimination or restriction of hexachlorobutadiene (HCBD), polychlorinated napthalenes (PCNs), pentachlorophenols (PCPs) and their salts and esters, as well as decabromodiphenyl ether (DecaBDE) and short-chained chlorinated paraffins (SCCPs), with immediate effect. This regulation enforced a prohibition on the production, use, import, and export of the chemicals, although certain uses of DecaBDE and SCCPs have received exemptions. Consequently, this brought the total number of chemicals ratified by China to 28 (Yake, 2023).

Indonesia

Indonesia signed the Convention in 2001 and ratified it in 2009. The country initially developed its NIP in 2008, focusing on the initial 12 POPs, and subsequently updated it in 2014 to incorporate newly added POPs i.e., α – hexachlorocyclohexane, α – hexachlorocyclohexane, chlordecone, hexabromobiphenyl, Octa-BDE, lindane, pentachlorobenzene, PFOS, endosulfan, and HBCDD (COP 6 Amendments, Indonesia, n.d.). While Indonesia's regulations do not cover all POPs, the NIP addresses the regulation of POPs and pesticides throughout their life cycle. Apart from listing all existing regulations pertaining to recently ratified eight POPs under SC, it also provides additional details on the production, use, disposal, and contamination data of various POPs in Indonesia.

The current regulations primarily govern a subset of chemicals and pesticides under the POPs category. However, there are three specific POPs—PFOS and related substances, PBDEs (including tetrabromodiphenyl ethers, pentabromodiphenyl ethers, hexabromodiphenyl ethers, and heptabromodiphenyl ethers), and HBCDs—whose life cycle stages are not regulated. The NIP acknowledges the limited availability of quantitative data concerning POPs, stockpiles, and contaminated soil in Indonesia. It also highlights that certain hazardous pesticides were still registered and in use within the country.

Indonesia submitted a Review and Update of its NIP in November 2021. The document covers the POPs targeted in the 2014 NIP, as well as the nine new POPs added to the Convention between COP-5 and COP-9 (namely, endosulfan, HBCD, chlorinated napthalenes, HCBD, PCP, deca-BDE, SCCP, PFOA, and dicofol). The updated NIP includes an evaluation of the implementation of the 2014 NIP, along with an action plan for future implementation (COP 9 Amendments, Indonesia, n.d.) .

The 2014 NIP reported that there was neither production nor export of POP-pesticides, including both initial and new POPs-pesticides. While there were no imports of initial POPS, certain new POPs like chlordecone, endosulfan, lindane, pentachlorophenol, and dicofol, were still being imported. The revised NIP highlighted a lack of data concerning stockpiles and POPs contamination. There are no records available for stockpiles, contaminated sites, and contaminated waste for HCBD, PCN, PCP, SCCP, POP-BDEs, HBB, and PFOS including its salts and PFOS-F, from 2015 to 2020. The NIP provides an inventory of PCBs updated up to 2015-2016. However, it is noteworthy that no specific arrangements have been made to restrict HBCD, PCNs and SCCPs, under the existing laws.

4.3 National Implementation Plan-Update, Review, and Implementation

India submitted its first NIP for the SC in 2011, five years after India's ratifying the Convention in 2006. The NIP was developed through a comprehensive assessment of the initial 12 POPs, commonly known as "dirty dozen". While the NIP provided a better understanding and overview of the status of the original 12 legacy POPs in India, it has not been updated since then to include the new POPs added to the Convention.

In 2011, after due consultation process between Indian Ministry of Environment, Forest and Climate Change, UNIDO- India, Central Pollution Control Board (CPCB), Delhi Central Power Research Institute (CPRI), Bangalore Hindustan Insecticides Limited (HIL), New Delhi National Environmental Engineering Research Institute (NEERI), and Nagpur National Institute for Interdisciplinary Science and Technology (NIIST), Thiruvananthapuram, the government identified the following key priority areas for the implementation of NIP:

- Environmentally Sound Management and Final Disposal of PCBs and PCB-containing wastes
- Environmentally Sound Management of Medical Wastes (electrical equipment, etc.)
- Development and promotion of non-POPs alternatives to DDT
- Implementation of the Best Available Technology (BAT)/ Best Environmental Practices (BEP) strategies for

elimination / reduction of unintentional POPs emissions of the priority industry sectors identified in the NIP.

- Management of PVC plastic waste to avoid incineration / dumping the landfill for preventing releases of dioxins and furans due to burning
- Capacity building, demonstration of production and promotion of bio-botanical neem derived bio-pesticides as viable, eco-friendly, bio-degradable alternatives to POPs pesticides
- Identification of POP contaminated sites and of remediation process of the potential POP pollution hotspots
- POPs and pesticides management in India
- Inventorization of newly listed POPs
- National POPs monitoring India programme and
- Strengthening institutions and capacity building for effective and efficient implementation of the NIP in India

Further, to effectively implement the NIP under the Convention, India strategically mooted its plan from 2011 to 2022 in three phases, namely, immediate priorities, medium term- and long term-priorities.

The status of the initial 12 POPs under the SC is summarized in **Table 4.4**.

International support on POPs Management in India

After submission of the NIP on POPs in 2011, three large projects were initiated in India with the support from GEF. These projects include: 1) Environmentally sound management and final disposal of PCBs in India (GEF ID: 3775); 2) Environmentally Sound Management of Medical Wastes in India (GEF ID: 3803) and 3) Development and promotion of non-POPs alternatives to DDT (GEF ID: 4612). Since then, these projects have made a notable progress on the

Table 4.4: Status of initial 12 POPs under the SC

Sl. No	Chemical	Annex to the SC	Category	Current Status in India
1	Aldrin	A	Pesticide	Banned through gazette notification on September 20, 1996, by Ministry of Agriculture & Farmers Welfare
2	Dieldrin	A	Pesticide	Banned through gazette notification on July 17, 2001, by Ministry of Agriculture & Farmers Welfare
3	Endrin	A	Pesticide	Banned through gazette notification on May 15, 1990, by Ministry of Agriculture & Farmers Welfare
4	Chlordane	A	Pesticide	Banned through gazette notification on September 20, 1996, by Ministry of Agriculture & Farmers Welfare
5	Heptachlor	A	Pesticide	Banned through gazette notification on September 20, 1996, by Ministry of Agriculture & Farmers Welfare
6	Mirex	A	Pesticide	Banned through gazette notification on March 27, 2014, by Ministry of Agriculture & Farmers Welfare
7	Toxaphene	A	Pesticide	Banned through gazette notification on July 25, 1989, by Ministry of Agriculture & Farmers Welfare

Sl. No	Chemical	Annex to the SC	Category	Current Status in India
8	Hexachlorobenzene (HCB)	A & C	Pesticide/ Industrial Chemical/ Byproduct	Banned through gazette notification on March 27, 2014, by Ministry of Agriculture & Farmers Welfare
9	PCB	A & C	Industrial Chemical/ Byproduct	Gazette notification for PCB regulation "Regulation of Polychlorinated Biphenyls Order, 2016" issued by the Ministry of Environment, Forest and Climate Change (MoEF&CC) on April 6, 2016
10	DDT	A	Pesticide	DDT use for the domestic public health programme is restricted up to 10,000 metric tonnes per annum, except in case of any major outbreak of epidemic. M/s Hindustan Insecticides Ltd., the sole manufacturer of DDT in the country, may manufacture DDT for export to other countries for use in vector control for protecting public health. Export of DDT to Parties and State Non-Parties shall be strictly in accordance with the paragraph 2(b) article 3 of the Stockholm Convention on Persistent Organic Pollutants (POPs) (Gazette notification on March 27, 2014 by the Ministry of Agriculture & Farmers Welfare)
11	Dioxins (PCDD)	C	By-product	Standards available for specific industry under the Environmental (Protection) Rules, 1986
12	Furans (PCDF)	C	By-product	Standards available for specific industry under the Environmental60[89pl;joool (Protection) Rules, 1986

Note: Annex A: Elimination; Annex B: Restriction; Annex C: Unintentional production.

management of POPs pollution in India. A summary of these projects, and initiatives and outcomes within, is discussed below.

1. Environmentally Sound Management and final disposal of PCBs in India (UNIDO, 2009; GEF, 2009)

Considering that a major use of PCBs in India was in the power sector, CPRI (Bangalore) was the executing agency which was assigned the task of implementing environmentally sound management and final disposal of PCBs in India. The overall project objective was to reduce and eliminate the use and releases of PCBs to the environment through promotion of various measures to minimize exposures and risks and by introducing environmentally sound management and disposal techniques for PCBs, PCB-containing equipment, and PCB-containing mineral oils and wastes. The project aims at the final disposal and complete elimination of entire PCBs inventory in India by 2025 and 2028, respectively.

As part of this project, a preliminary study was conducted by the CPRI from 2004 to 2008 partially to assess the PCB situation in India, which included the establishment of a preliminary inventory on PCB-containing electrical equipment and the evaluation of India's capacity for the environmentally sound management and disposal of PCBs. According to the NIP, around 9,837 tonnes of PCBs exist in the country and a detailed mapping was carried out to understand the status of these PCBs. The project was designed to achieve the removal of 7,700 tonnes of PCBs, PCB-containing equipment, and PCB-containing mineral oils and wastes from targeted sites and transport them to the disposal unit; and then dispose the 7,700 tonnes in an environmentally sound manner using the destruction facilities set up by the project. The project covers setting up of four facilities for dechlorination/destruction of PCBs out of which three are proposed at SAIL-BSP (Steel Authority of India-Bhilai Steel Plant) and one at CPRI, as described below:

1. Mobile dechlorination unit hosted by CPRI for *in situ* removal and treatment of low-PCB containing mineral oils. It has a capacity of 4 MT per batch run over 2 days, hence providing a yearly destruction capacity of up to 600 MT/year.
2. Plasma system (Plascon process) for destruction of pure PCBs (at BSP?) with a capacity of 1 MT/day.
3. Dechlorination treatment plant for low level PCBs, discarded PCB containing equipment and other PCB containing waste (at BSP), with a capacity of 1.7 MT per batch.
4. The dismantling of transformers and other equipment can result in a further waste stream of porous materials, like wood, paper, etc., which are contaminated with PCB-containing oils. Hence, a further indirect thermal desorption unit is being set up to remove the PCB-containing oil from this porous material with a daily capacity of 1,000 kg/day.

The mobile dechlorination facility by CPRI has been commissioned and is fully operational to treat low-level PCBs containing oil at owner's sites. On March 2021, it was reported that CPRI dechlorinated 231 MT of PCB contaminated oil through its mobile chlorination facility having a capacity of 600 MT/year. However, other facilities at BSP are still at advanced stage of completion (SAIL, n.d.).

2. Environmentally Sound Management of Medical Wastes in India with focus on POPs (GEF, 2011; UNIDO, 2021)

The National Implementation Plan identified the "Environmentally Sound Management of Medical Waste" as a priority for the POPs management in India. In this context, the project on Environmentally Sound Management of Medical Wastes in India or (ESMWI) was approved by the GEF for implementation and execution by the UNIDO and the Ministry of Environment, Forest and Climate Change (MoEF&CC) in 2011. The project aimed to reduce and ultimately eliminate the releases of unintentionally produced POPs (u-POPs) and other harmful pollutants of global importance into the environment while assisting India in fulfilling its relevant obligations under the SC. It was expected to promote the country-wide adoption of best available techniques/best environmental practices (BAT/BEP) in the health care institutions. This approach aimed to reduce adverse environmental impacts and protect human health. A few notable advancements made under this project are listed below.

1. The Biomedical Waste Management (BMWM) Rules, 2016 (notified vide Gazette Notification No. G.S.R 343 (E) dated 28th March 2016) in supersession of the Biomedical Waste (Management & Handling) Rules 1998. Further amendments to BMWM Rules, 2016 were notified on 16th March 2018, 20th February 2019, and 13th May 2019.

- *Stringent dioxin and furans emission standards has been included in the new BMWM Rules and compliance to the rule provisions is taken care of by the prescribed authorities at the national and state levels, as per Rule 9 Schedule III of BMWM Rules, 2016.*
- *State enforcement mechanisms were well defined in the new BMWM Rules, 2016.*

2. Development of Guidelines for Management of Healthcare Waste in Health Care Facilities as per Biomedical Waste Management Rules, 2016.
3. Revised simplified colour categorization of biomedical wastes, phase out use of chlorinated blood bags and gloves, and stringent emission standards for *Common Biomedical Waste Treatment Facility* (CBMWTF) have been notified, which will help in achieving the objectives of Stockholm Convention.
4. Secondary chamber of the five identified CBMWTF incinerators were upgraded to achieve reduction of dioxin and furans. The emission of dioxin and furans from BMW incinerators were measured post-upgradation and found to be complying as per BMWM Rules, 2016.

3. Development and promotion of non-POPs alternatives to DDT (GEF, 2022)

One of the top priorities of the India's NIP is identifying and introducing alternatives to DDT which was exempted for use in the country for prevention of vector-borne disease such as malaria, dengue, and *kala-azar*. This GEF approved project of 2015 aimed to introduce bio- and botanical pesticides and other locally appropriate cost-effective and sustainable alternatives to DDT as the first step towards reducing and consequently eliminating its dependency, meanwhile also ensuring food safety, enhancing livelihood, and protecting human health and the environment. The transfer of environmentally sound technologies by GEF & UNEP to the Government of India for manufacturing of non-POPs alternatives to DDT can provide financially comparable alternatives to DDT use in the country that would eventually lead to a gradual phaseout of DDT produced and used in India.

Some of the major achievements of this project were:

1. A draft action plan "to recommend necessary changes in the legal and institutional framework to the alternatives to DDT" was prepared and shared with the MoEF&CC of India.
2. Under a GEF project in 2022, the guidance documents for producers, registration holders and users of DDT alternatives for vector control [Long-Lasting Insecticidal Nets (LLINs), Bt (*Bacillus thuringiensis*)-based products and neem-based products] were developed to help them fulfil the legal requirements for alternatives to DDT.
3. Four training modules on Integrated Vector Pest Management (IVPM) were developed and approved by the National Center for Vector Borne Diseases Control (NCVBDC) for pilot testing.
4. Practical training courses based on IVPM training modules were developed.

Review and Update of NIP in India under the SC on POPs

Under Article 7, the Parties to the SC are required to review and update their NIPs regularly, considering the regular addition of chemicals to the Annexes of the SC (Stockholm Convention, 2004). Moreover, Article 15 requires each Party to report to the Conference of the Parties (COP), every four years, on the measures taken to implement the SC provisions and their effectiveness in meeting its objectives. Therefore, the countries need to update their respective NIP (considering collection of qualitative and quantitative data) to enable participating countries to comply with the Article 15 of the SC.

In this context, the GEF has approved a project in 2022 to review and update India's NIP for the SC, with the UNEP serving as the Implementing Agency (GEF, 2023). On the recommendations of the MoEF&CC, the new project was granted to CSIR-NEERI with support from the CPCB, CSIR-NIIST (Trivandrum) and CSIR-IITR (Lucknow). The project is coordinated by the MoEF&CC, and a National Coordination Committee (NCC) has been constituted

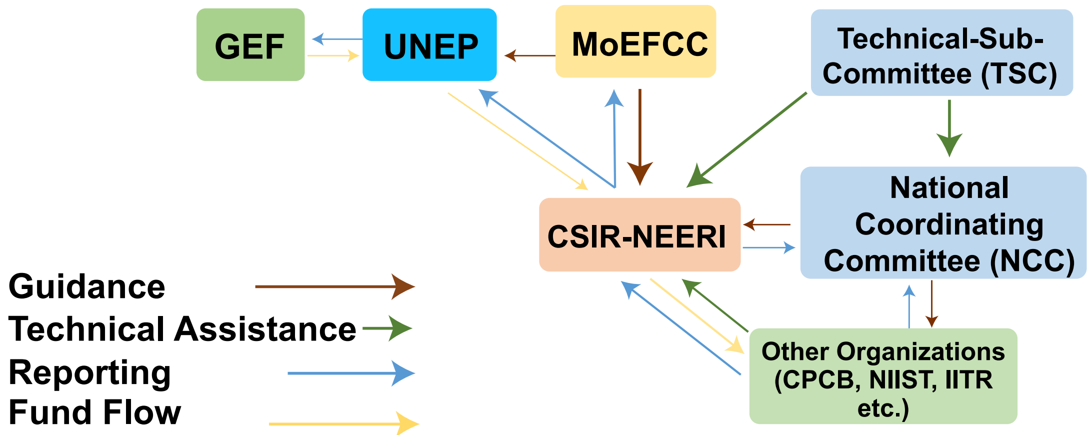

Figure 4.1: The scheme presenting an overview of the Institutional Framework for Project Implementation at the National Level in India

for providing guidance, review, and policy support to all the executing agencies involved. Moreover, a Technical Sub-Committee has also been established by the MoEF&CC to provide technical assistance to CSIR-NEERI and NCC.

The following gaps & challenges were identified in NIP's development/update process in Indian context:

- *Infrastructure:* Need for capacity building in qualitative and quantitative identification of POPs releases in various environment matrices.
- *Country Baseline Data on POPs:* Need for primary and secondary data to identify the hotspots and delineate the country situation on POPs.
- *Institutional Policy and Regulatory Framework:* Existing regulations need to be better enforced and periodically updated to include newly added POPs to SC.
- *Reduction and elimination of POPs:* Development of modern waste management practices to eliminate new POPs and candidate POPs circulating in the market and the environment.
- *Human resources and capacity:* Conducting regular training of manpower for the measurement of POPs releases, evaluating POPs alternatives, implementation of effective laws and regulations, data evaluation, environmental risk assessment and management.

The Government of India is in the process of updating the NIP to include the newly ratified seven POPs and all the chemicals currently listed in the SC. The aim of NIP updation is to:

1. Build political support and stakeholder involvement in NIP development, endorsement, and its implementation in future.
2. Develop tools and methodologies to be used in India to facilitate the NIP development, review, and update process and its implementation.
3. Support India in developing, reviewing, and updating the NIPs, and complete their national reporting following the methodologies development by the SC Secretariat and approved by the COP.
4. Ensure development of knowledge products, sharing of knowledge, development of platforms for information exchange and training/familiarisation, and knowledge management and reporting at the global level is reached; and
5. Ensure effective monitoring and evaluation.

There are several institutions involved in developing, implementing and updating the NIP in India. The MoEF&CC, NCC and UNEP are responsible for the overall coordination and guidance/monitoring. The other participating organisations and their assigned tasks are given below:

- *CSIR-NEERI:* Data collection on Pesticidal POPs (15 chemicals) and 8 Industrial Chemicals.
- *CSIR-IITR (Lucknow):* Data collection on PFAS group of Industrial Chemicals.
- *CSIR-NIIST (Trivandrum):* Overseeing the work on Unintentional POPs (7 chemicals).
- *CPCB* and *SPCBs* are responsible for coordinating sampling and industrial visits for this project.

Throughout the project implementation process, priority will be given to the consultation with and involvement of relevant national, regional and international stakeholders. The development of updated NIP can provide help India in identifying the activities and implement post-NIP projects in accordance with the requirements of the SC. In addition, UNEP, through its Special Programme on Chemicals and Waste, is working with CSIR-NEERI to enhance institutional capabilities for chemicals and waste management in India, with a particular emphasis on POPs considering the national needs and emerging issues. This project aims at (a) improving awareness regarding the POPs, (b) checking the available environmentally sound management practices for proper implementation, and (c) implementation on handling, storage, and disposal of chemical and wastes management. The project has also created a special Directorate comprising of experts from across the country to support the implementation of SC in India and to provide necessary support in managing hazardous chemicals and waste in India.

It is important to highlight that no comprehensive inventory update activities were implemented in India after the first NIP was completed in 2011. This has resulted in a huge information gap on POPs in the country. Therefore, the NIP update process presents an opportunity to bring together stakeholders from various levels, such as relevant ministries and departments, Central and State Pollution Control Boards, industries including MSMEs, industry associations, research and academia, and CSOs etc. Further, it is expected that the new NIP updating process will help create new data and information on new and old POPs, and will help in improving the expertise and capacity for analysis of new POPs in the country. The present status of the POPs listed under the SC and not ratified by India is provided in **Table 4.5**.

Table 4.5: Status of POPs that are not yet ratified in India

Chemical	Category	Annex to the SC	Adopted in SC	Current Status in India
Alpha-HCH	Pesticide/ By-product	A	COP-4	Intentional use as pesticide has been phased out, produced as by-product during the production of lindane.
Beta-HCH	Pesticide/ By-product	A	COP-4	Intentional use as pesticide has been phased out, produced as by-product during the production of lindane.
Lindane (gamma-HCH)	Pesticide	A	COP-4	Banned for manufacture, import and use by gazette notification on March 25, 2011 by the Ministry of Agriculture & Farmers Welfare Exempted for Human health pharmaceutical for control of head lice and scabies as second line treatment under SC

Chemical	Category	Annex to the SC	Adopted in SC	Current Status in India
Perfluorooctane sulfonic acid, its salts and perfluorooctane sulfonyl fluoride	Industrial Chemical	B	COP-4	No information on production in India. Listed with specific exemptions and acceptable purpose in SC
Technical endosulfan and its related isomers	Pesticide	A	COP-5	Banned by the Supreme Court of India w.e.f. 13-05-2011 for production, use & sale all over India vide ad-Interim order in the Writ Petition (Civil) No. 213 of 2011 and finally disposed of in Jan 2017
Pentachlorophenol, its salts and esters	Industrial Chemical	A	COP-7	India opposed listing of PCP during COP-7 Banned for manufacture, import and use as pesticide.
Polychlorinated naphthalenes	Industrial Chemical	A & C	COP-7	No information available on use and production of PCNs. However, it is banned in printing ink for food packaging under BIS standard IS 15495:2004
Short Chain Chlorinated Paraffins	Industrial Chemical	A	COP-8	Listed with specific exemptions for certain applications in SC No information on production and use in India
Dicofol	Pesticide	A	COP-9	India announced stopping the production of dicofol during the COP-9 Ministry of Agriculture & Farmers Welfare came up with a draft "Insecticides (Prohibition) Order, 2023" on 2nd February 2023 banning registration, import, manufacture, formulation, transport, and sale of dicofol. However, the draft is yet to be notified.
Perfluorooctanoic Acid, its salts and PFOA-related compounds (PFOA)	Industrial Chemical/ Pesticide	A	COP-9	India supported its listing during the COP-9 No regulation in India. No information on production and use in India

Chemical	Category	Annex to the SC	Adopted in SC	Current Status in India
Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds	Industrial Chemical	A	COP-10	No regulation in India. No information on production and use in India
UV-328	Industrial Chemical	A	COP-11	Listed with specific exemptions for certain applications in SC No regulation in India. No information on production and use in India
Dechlorane Plus	Industrial Chemical	A	COP-11	Listed with specific exemptions for certain applications in SC No information available on the export and import of DP in India. In 2020 the Society of Indian Automobile Manufacturers (SIAM) submitted to the POPRC that DP is used as an alternative to c-decaBDE in automobile manufacturing
Methoxychlor	Pesticide	A	COP-11	No information on production and use in India

Annex A: Elimination; Annex B: Restriction; Annex C: Unintentional production.

4.4 Management of POPs in India

Some of the key aspects of India's management of POPs are discussed below.

1. **SC on POPs:** India ratified the SC on POPs on 13th January 2006 and the Convention came into force on 13th April 2006. India is now a party to the SC on POPs. The Central Government through the MOEF&CC has derived its power to negotiate the various Conventions including SC, and develop frameworks based on the outcome of the negotiation of the Convention. To implement the commitments of the SC, the Ministry notified the Regulation of Polychlorinated Biphenyls Order, 2016; and Regulation of Persistent Organic Pollutants Rules, 2018 to prohibit production, import and use of hazardous chemicals. In India, both legal and management aspects related to protection from chemical risks are part of the responsibilities of the Central Government, which are discharged through the State Departments and a range of governmental agencies that manage various aspects of chemical pollution. The resulting legislative and executive frameworks are comprehensive but fragmentary

because different stages of the management of chemicals (registration, production, import, etc.) are under the jurisdiction of different authorities. The MoEF&CC is the focal ministry for SC. However, the Union Ministry of Agriculture and Farmers Welfare has the sole authority to make rules on managing pesticides regarding environmental contamination due to pesticidal POPs (CPCB, n.d.).

2. **National Implementation Plan (NIP):** India has developed a NIP to fulfil its obligations under the SC. The plan outlines strategies and measures for the reduction and elimination of POPs in various sectors (TERI 2018). The priorities and strategies in India's NIP on POPs have been discussed earlier.
3. **Regulatory Framework:** India has enacted and strengthened regulations to control the production, use, import, export, and disposal of POPs. The Ministry of Environment, Forest, and Climate Change (MoEF&CC) is the nodal authority responsible for overseeing and implementing these regulations.
4. **Capacity Building and Awareness:** Efforts have been made to build capacity at various levels, including training programmes (for enforcement agencies), awareness campaigns, and public education about the hazards of POPs. This involves collaboration between government agencies, non-governmental organizations (NGOs), and the private sector.
5. **Monitoring and Surveillance:** India has been involved in monitoring and surveillance activities to assess the levels of POPs in the environment, wildlife, and human populations. This includes establishing laboratories and monitoring networks to track the presence of POPs and their potential impacts.
6. **Alternatives and Best Practices:** Promoting the use of alternatives to POPs and adopting best practices in various industries are integral parts of India's strategy. This involves encouraging industries to adopt cleaner production processes and technologies.
7. **Way forward for management of POPs** may include the following Toxics Link, 2018:

- Provision of a national coordination and consultation cell in India's MOEF&CC to coordinate with the concerned departments and agencies involved in POPs management.
- Adequate allocation of financial resources for POPs management, with audit at fixed intervals.
- Enhancement of monitoring capacity of the stakeholders, mostly state government agencies, and other regulatory agencies and NGOs.
- Bridging data gaps associated with POPs use, release, presence, health impacts in India.
- Establishment of a sound dissemination plan with scope of information dissemination and large public outreach for adverse effects of POPs and their presence in the immediate environment. Utilisation of mainstream media for information, dissemination, and awareness on POPs.
- Prioritizing the food safety issues in the context of POPs, with adequate labelling and regulatory mechanisms in place.
- Setting up adequate infrastructure/laboratory facilities for monitoring and analysis of POPs with periodic reporting by the concerned agencies to get the updated information.
- Industries need to be proactive and should voluntarily phase out POPs as well as share inventories and data.
- Strengthening and capacity building of the customs department for inspection, vigilance and standardisation of procedures for the same, to check the illegal export and import of POPs.
- Capacity building of NGOs to serve as a watchdog for effects, release patterns and health impacts of POPs as well as advocate for their phaseout based on impacts on industrial workers.
- Periodic updating of the website on SC with the latest developments/data on POPs.

4.4.1 Best Available Technology (BAT)/ Best Environmental Practices (BEP) in India

i. **BAT/BEP in NIP:** India's NIP under the SC includes strategies and measures to implement BAT/BEP for the reduction and elimination of POPs. The plan outlines how the country intends to incorporate these principles into various sectors to minimize the environmental impact of persistent organic pollutants. Five years after the Indian government ratified the SC, the National Plan of India on POPs was unveiled in 2011 (NIP India, 2011). After a status assessment of the 12 first POPs, labelled the "dirty dozen," the NIP was created to determine the best course of action for their eradication from the nation. Numerous national authorities and universities conducted the inventory and assessment of these POPs (Mohapatra et. al., 2023).

ii. **Sector-Specific Initiatives:** India has been focusing on sector-specific initiatives to adopt BAT/BEP practices. This includes industrial sectors such as chemicals, pesticides, and waste management, where measures are taken to promote cleaner production processes and technologies. There is, however, a need for holistic management of different sectors to achieve the regulatory levels of chemicals that India is aiming for.

iii. **Capacity Building:** Capacity building initiatives have been undertaken to train and educate professionals, regulators, and industry stakeholders about BAT/BEP principles. This involves creating awareness about the importance of adopting environmentally sound practices and technologies.

iv. **International Collaboration:** India collaborates with international organizations and agencies to share knowledge and experiences related to BAT/BEP. This collaboration facilitates the exchange of best practices and technologies that can contribute to the effective implementation of these principles.

4.5 Measuring regulatory performance: Analysis of existing Regulations and Policies in India

4.5.1 Assessment of regulation and policy enforcement and implementation

The SC is a key international treaty that provides regulatory framework and guidance for the management of Persistent Organic Pollutants (POPs). The SC initially recognised 12 chemicals as POPs known as "dirty dozen" fulfilling the criteria of causing adverse effects on the environment. As of now 34 chemicals are listed as POPs by the SC. After the ratification of SC in 2006, India came out with the NIP in 2011 (NIP India, 2011). The NIP was prepared after an assessment of the status of 12 initial POPs and took appropriate actions for their elimination. Many of these 12 POPs were pesticides, and the government took initiatives to phase them out even before the ratification of SC. Out of 22 new POPs listed by the SC (after the dirty dozen), India showed reservations on inclusion of some of them including Endosulfan, Pentachlorophenol and its salts and esters, and sought exemption on the use of chemicals like Deca-bromodiphenyl ether (commercial mixture, c-deca-BDE), etc. for automobile and textile sectors. Subsequently, India ratified seven more POPs and is currently updating the NIP to manage these new POPs.

Status of management of old POPs (Initial 12 POPs)

1. Pesticidal POPs

India completely banned all the chemical pesticides for agricultural use, which were designated as POPs and were known as dirty dozen. The NIP has a detailed action plan to dispose these pesticides in an environmentally sound manner. including HCB and Mirex, which were never registered in India. Out of the banned pesticides, the stockpiles of Aldrin and Dieldrin were identified in the NIP and an action plan was proposed to eliminate them within a year in an environmentally sound manner.

2. Status of DDT

India banned the use of DDT as a pesticide in agriculture since 1987, but it is still used for vector control. The usage of DDT is allowed for the domestic public health programme, with restriction of up to 10,000 Metric Tonnes per annum, except in case of any major outbreak of epidemic. HIL India, a public sector enterprise, is the only manufacturer of DDT in India (as well as globally) and also export DDT to a few malaria-affected African nations for their malaria control programme. India registered with the SC Secretariat for the specific exemption of DDT as an intermediate in the production of Dicofol in close system in batches. However, Dicofol production has been discontinued in India since 2023 .The production of DDT has decreased substantially since the last few years, and is committed to phase out production by 2024.

Presently, to phase out the DDT, the GEF approved a project on "Development and promotion of non-POPs alternatives to DDT". The project aim was to introduce bio- and botanical pesticides (long-lasting insecticidal nets (LLINs), Bt-based biopesticides, and neem-based biopesticides) and other locally appropriate cost-effective and sustainable alternatives to DDT as first step for reduction and consequent elimination of dependency on DDT. This project has made significant progress in introducing and promoting sustainable alternatives to DDT, reducing dependency on DDT, and ensuring the long-term viability of pest control practices.

3. Phasing out PCBs

According to NIP, India has 9,838 tons of PCB containing oils including retro filling, with 70% in the power sector. The MoEF&CC came out with the "Regulation of Polychlorinated Biphenyls Order, 2016" on April 6, 2016, which will phase out and eventually ban the manufacture, import and use of PCBs in India. According to the Regulation, the PCBs will be banned in 2 stages:

1. The manufacture and import of PCBs and the import of equipment containing PCBs were banned immediately from the date of publication of the Order in 2016.
2. The use of PCBs of any other form shall be completely prohibited by December 31, 2025.

According to the regulations, the import, export, or trade of equipment contaminated with PCBs is subject to control under the Hazardous Waste Management Rules. The disposal of waste PCBs or PCB-contaminated equipment must also be carried out in accordance with the provisions of the Hazardous Wastes (Management, Handling, and Transboundary Movement) Rules, 2008, by December 31, 2028. Any existing stockpiles of PCBs must be destroyed in an environmentally beneficial manner by the same deadline. In the meantime, before PCBs are totally banned, equipment containing PCBs must be maintained and stored properly to avoid any leakage into the environment. The occupiers should declare the total quantity of PCBs they possess and equipment containing PCBs to the MOEF&CC within one year of publication of order (by 6th April 2017). Also, the regulation prohibited the discharge of PCBs directly or indirectly on land, in surface water or effluent treatment plant from defective, out of use or in use PCBs-containing equipment.

The GEF supported to post NIP project on PCBs that aimed to demonstrate the feasibility of the Action Plan for disposal of PCBs specified in NIP in selected states and eliminate 1700 tonnes of pure PCBs and 6000 Tonnes of PCB containing equipment and wastes as the first step in NIP implementation. The CPRI in collaboration with MoEF&CC and UNIDO came up with "Guidelines for PCBs Waste Identification, Tracking and Record Keeping" as well as "Guidelines for PCBs, PCB-Containing Equipment and Waste Interim Storage" in 2015. A mobile dechlorination facility has been commissioned by CPRI and is fully operational to treat low level PCBs containing oil at the owner's sites.

The facilities were also planned at Bhilai Steel Plant of Steel Authority of India (SAIL), consisting of static plant containing plasma incinerator (Plascon system) with capacity of 1 MT/day and de-chlorination unit of capacity of 1.7 MT per batch. The dismantling of transformers and other equipment can result in a further waste stream of porous materials, like wood, paper, etc. which are contaminated with PCB containing oils. Hence, a further indirect thermal desorption unit is being set up to remove the PCB-containing oil from this porous material with a daily capacity of 1,000 kg/day. The yearly decontamination capacity of porous material is 330 MT/year. This would generate estimated amount of 200 MT/year low concentration PCB waste, which is to then be treated in the dechlorination unit to destruct the PCBs.

4. Regulations on dioxins (PCDD) and furans (PCDF)

In 2009-2010, the first inventory of the annual PCDD/F releases were calculated using the UNEP Toolkit that was estimated to be 8656.55 g TEQ. In this context, an action plan was proposed in the NIP with the objective of achieving significant PCDD/F release reduction by 2015. In 2022, the World Health Organization (WHO) organised an expert panel in Lisbon (Portugal) in which the 2005 WHO TEFs for chlorinated dioxin-like compounds were re-evaluated. India's Environmental (Protection) Act, 1986, serves as the overarching legislation for environmental protection, and it contains specific provisions to regulate industrial chemicals, including some POPs. Under this Act, the Government of India published the Solid Waste Management Rules, 2016; Biomedical Waste Management Rules, 2016 and Hazardous Waste Management Rules, 2016, which prescribed emission standards for dioxins and furans from waste incinerators. These regulations align with India's commitment to reducing unintentional POPs, in line with its obligations under the SC. For the reduction of dioxins and furans, specific provisions were provided in the Biomedical Waste Management Rules, 2016:

1. Phasing out use of chlorinated plastic bags (except urine bags, effluent bags, abdominal bags, and chest drainage bags), gloves and blood bags by 2018.
2. Waste to be incinerated shall not be chemically treated with any chlorinated disinfectants.
3. Waste to be treated using plasma pyrolysis or gasification shall not be chemically treated with any chlorinated disinfectants and chlorinated plastics shall not be treated in the system.

Similar provisions, such as waste to be incinerated not to be chemically treated with any chlorinated disinfectants and incineration of chlorinated plastics to be phased out by 2018, were also made under the Solid Waste Management Rules 2016. The Hazardous Waste Management Rules 2016 bans wastes containing, consisting of, or contaminated with any congener of PCDF or PCDD under Schedule VI of the Rules (wastes that are banned from import). The CPCB also formulated guidelines under the respective Waste Rules for monitoring and reducing dioxins and furans. For example, under Biomedical Waste Management Rules, 2016, the CPCB formulated guidelines for monitoring compliance of the Common Biomedical Waste Treatment Facilities by State Pollution Control Boards, including monitoring of emissions of total dioxins and furans to ensure compliance with the Rules. Under the Environment (Protection) Rules, 1986, emission standards to limit the concentrations of dioxins and furans released from some industries have also been provided. For example, Standards for Pesticide Industry limit the emissions of total dioxins and furans to 0.2 ng TEQ/Nm^3, for existing incinerators, and 0.1 ng TEQ/Nm^3, for new incinerators. Even older incinerators were mandated to comply with the lower limit by 18th August 2013.

Status of management of new POPs

On March 5, 2018, the MoEF&CC notified the Regulation of POPs Rules that ban the manufacture, trade, use, import and export of the seven new POPs **(Table 4.6)** listed under the SC. These POPs include pesticides, industrial chemicals and unintentionally released substances from industrial processes. Many of these new POPs are brominated flame retardants linked to the plastic-based products like electronic industry, automobile industry, toy industry and textile industry. The Rules prohibit manufacture, trade, use, import and export of the seven chemicals given below. This was one of the important steps from the Government of India towards ratification of newly listed POPs and thus, towards implementation of SC obligations. After the POPs Rules 2018 came into the force, the Indian Cabinet ratified these seven POPs on 7th October 2020 and delegated its powers to the MoEF&CC and Ministry of External Affairs to ratify

Table 4.6: Details of seven POPs recently ratified the Government of India

Chemical	Category	Annex to the SC	Adopted in SC
Chlordecone	Pesticide	A	COP-4
Hexabromobiphenyl	Industrial Chemical	A	COP-4
Hexabromodiphenyl ether and heptabromodiphenyl ether (commercial octa-BDE)	Industrial Chemical	A	COP-4
Tetrabromodiphenyl ether and pentabromodiphenyl ether (commercial penta-BDE)	Industrial Chemical	A	COP-4
Pentachlorobenzene	Pesticide/Industrial Chemical/By-product	A & C	COP-4
Hexabromocyclododecane	Industrial Chemical	A	COP-6
Hexachlorobutadine (HCBD)	Industrial Chemical	A & C	COP-7 and COP-8

Annex A: Elimination; Annex B: Restriction; Annex C: Unintentional production.

additional chemicals under SC which are already regulated under domestic regulations thereby streamlining the process.

Other Regulations and Policies to manage new POPs

In addition to the ratification of seven new POPs, India also came up with regulations and restriction on the other new POPs (**Table 4.7**).

India has come up with the provisions for reducing hazardous substances (RoHS) in the manufacturing of electrical and electronic equipment (EEE) under the E Waste (Management and Handling) Rules 2011, which were updated in 2016 and subsequently in 2022. It mandates that every producer of EEE and their components shall ensure that their new electrical and electronic equipment and their components or consumables or parts or

Table 4.7: Some additional POPs regulated by the Government of India

Chemical	Category	Annex to the SC	Status in India
Alpha-HCH	Pesticide/By-product	A	Intentional use as pesticide has been phased out, produced as by-product during the production of lindane.
Beta-HCH	Pesticide/By-product	A	Intentional use as pesticide has been phased out, produced as by-product during the production of lindane.
Lindane (gamma-HCH)	Pesticide	A	Banned for manufacture, import and use by gazette notification on March 25, 2011, by the Ministry of Agriculture & Farmers Welfare

Chemical	Category	Annex to the SC	Status in India
Technical endosulfan and its related isomers	Pesticide	A	Banned by the Supreme Court of India w.e.f. 13-05-2011 for production, use & sale all over India vide ad-Interim order in the Writ Petition (Civil) No. 213 of 2011 and finally disposed of in Jan 2017
Pentachlorophenol	Pesticide/ Industrial Chemical/ Byproduct	A & C	Banned for manufacture, import, and use by gazette notification by the Ministry of Agriculture & Farmers Welfare
Polychlorinated naphthalenes	Industrial Chemical	A & C	It is banned in printing ink for food packaging under BIS standard IS 15495:2004
Dicofol	Pesticide	A	Ministry of Agriculture & Farmers Welfare came up with a draft "Insecticides (Prohibition) Order, 2023" on 2nd February 2023 banning registration, import, manufacture, formulation, transport, and sale of dicofol. However, the draft is yet to be notified.

Annex A: Elimination; Annex B: Restriction; Annex C: Unintentional production.

spares do not contain Pb, Hg, Cd, hexavalent Cr, PCBs, and PBDEs beyond a maximum concentration value of 0.1% by weight in homogenous materials for Pb, Hg, hexavalent Cr, PCBs and PBDEs and of 0.01% by weight in homogenous materials for Cd. Thus, the E waste rules have paved the way for the reduction of the BFR-POPs in electrical and electronic products in India. Further, the E -Waste Management Rules have detailed provisions for the environmentally sound management of the electrical and electronics products at the end of the life based on the principle of the extended producer responsibility.

Policy enforcement and implementation

Evidently, there are robust regulations in place in India to manage the environment since adoption of the Environmental Protection Act 1986. The Government of India ratified the SC in 2006 and subsequently initiated actions to address the twelve initial POPs. Interestingly, the Government banned some of the Pesticidal POPs even before ratification of the twelve POPs. The NIP has provided a detailed status including the stockpiles of Pesticidal POPs and other industrial POPs. The NIP has also assessed the status of the unintentional POPs (dioxins and furans). Although steps have taken to regulate or restrict new POPs directly or indirectly, it is important for India to regularly review and update its strategies and actions based on new scientific evidence, emerging technologies, and international developments in POPs management. Specific provisions can be added to regulate the production, use, import/export, and disposal of all the listed and emerging POPs. These limitations are:

- *Limited technical expertise:* Effective management of POPs often requires technical expertise and knowledge about their sources, pathways, and alternatives. Therefore, there is need of adequately trained resources to manage these new POPs which in India seems lacking.
- *Inadequate infrastructure:* The identification and management of POPs requires advanced and

specialized infrastructure, such as advanced laboratories and equipment for POPs monitoring and testing. For example, several incinerators have come up but there are only a few laboratories that can measure and monitor the release of dioxins and furans. Moreover, when India is looking forward to the incineration-based technologies, adequate human resources will be needed.

Enforcement and Compliance

Enforcing policies and ensuring compliance with POPs regulations can be difficult in a large and diverse country like India with varying levels of governance and enforcement capacity. State governments also have a critical role to play in dealing with POPs, so there is no need for a proactive approach on the part of state governments.

Public Awareness and Engagement

Overall, the management of POP requires a multi-sectoral approach involving multiple stakeholders. POPs are very uniquely varied chemicals, and the flow of information in the country is very poor. Therefore, continuous public and stakeholder awareness of POPs is necessary to ensure effective implementation of rules and regulations.

4.5.2 The socioeconomic analyses of regulated POPs

The socio-economic analysis of regulated POPs in India can be approached through the following steps:

1. **Understanding the Regulatory Framework:** India has a comprehensive set of environmental regulations to regulate POPs designated in the SC (Bharat et al., 2018; Toxics Link, 2018). However, various government departments and agencies at the central and state level have been authorised to regulate and manage the chemicals in the country. Depending upon the nature of the chemicals and their use and release, these institutions have different roles to play to manage the chemicals (including POPs) at different levels. Therefore, implementation of chemical regulations has been a challenge due to the overlapping of regulatory responsibilities, inadequate waste management and chemical pollution control, and a lack of a fundamentally retrospective approach towards environmental policy and risk management (Mohapatra et al., 2023).
2. **Identifying the Sources of POPs:** Because of their typical physical and chemical properties, POPs have complex behaviour in the environment. A complex interplay of processes that regulates intercompartment exchanges (such as diffusion across soil or water and air) and the co-transport with solids (such as contaminated particles in air and water) leads to the environmental cycling of POPs and, as a result, their environmental concentrations (Nizzetto et al., 2010). Additionally, secondary sources of POPs (referring to contamination of environmental matrices like soils, sediments and vegetation by POPs in the past) potentially represent a significant fraction of the total source inventory (Breivik et al., 2004).
3. Sources of POPs in India are not clearly defined, but typically include certain industrial and agricultural processes, and consumer products (Bharat et al., 2018). Currently, there is limited knowledge on the status of production, use, and release of specific POPs from developing countries (Dimmen et al., 2023). This necessitates the regular generation of adequate primary data through monitoring and source apportionment studies, which can be subsequently utilised for analysis and identification of sources, release and fate of POPs in India.
4. **Health Impact Assessment:** Given the persistent, bio-accumulative and toxic nature of POPs, assessing the health impacts of regulated POPs is crucial. These health impacts can manifest as both acute and chronic effects, especially on vulnerable population groups, potentially leading to a wide range of public health issues (Alharbi et al., 2018).
5. **Cost-Benefit Analysis:** This is crucial in determining the net benefit or cost of managing the impacts of regulated POPs. It involves assessing the costs associated with controlling the pollutants and estimating the benefits, such as improved

human health and environmental quality (UNEP/GEF 2017).

6. **Socioeconomic Impact Assessment:** It includes an analysis of the impacts of these chemicals on human health, the environment, and socio-economic conditions. The socioeconomic impact of POPs regulation also includes potential impacts on industries that use or produce these chemicals, as well as on individuals who may be employed in these industries or rely on products that contain these chemicals (Milic et al., 2019) (Melymuk et al., 2022). A 2019 Nordic Council of Ministers research on the "socioeconomic analysis of environmental and health impacts linked to exposure to PFAS" provides a good illustration. It points out that new sources of contamination, more individuals exposed, and increased remediation costs will result from continued inaction. The longer PFAS contamination persists in the environment without being remedied, the more groundwater or soil will need to be decontaminated and the further it will spread. **Figure 4.2** shows the impact pathway offering the general framework for socioeconomic analysis (Goldenman et al., 2019).

Policy Recommendations

Based on the above analysis, policy recommendations could focus on improving the enforcement of environmental laws, developing an integrated approach to pollution management, and developing strategies to mitigate health risks associated with POPs exposure. Policy framework must also provide an enabling environment for strengthening the capacity of stakeholders (Mohapatra, 2021). Additionally, raising public awareness about the dangers of POPs and the importance of sustainable living could complement these policy recommendations.

The conduct of a Socio-Economic Analysis for chemicals is challenging for both science and economics. There are important gaps in the lack of information not only in the impacts of chemicals on human health and the environment, but also, the

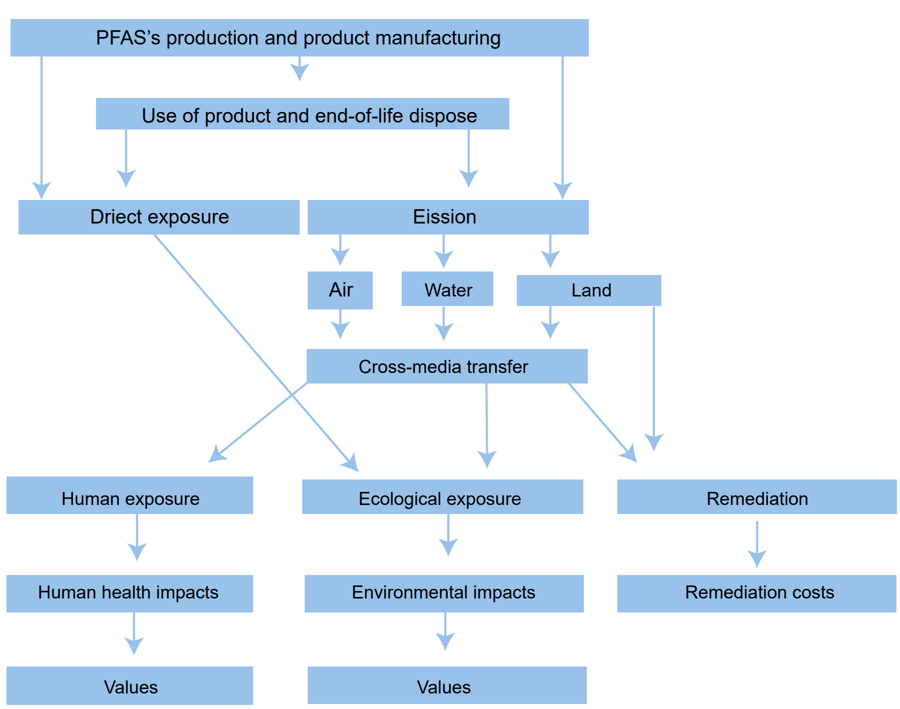

Figure 4.2: Framework for the socioeconomic analysis (*Goldenman et al., 2019*).

value to assign the identified impacts. However, socioeconomic evidence can be a powerful tool to support policymakers in regulatory decision-making and facilitates transparency in the decision-making process. Therefore, even with the associated challenges and uncertainties in conducting SEA, it is important to continue the practice and improve the methodologies and information associated in doing so.

4.6 Regulatory Framework and Policy on Chemicals and Waste in Tamil Nadu

Tamil Nadu is the most industrialised state in India in terms of number of factories and number of people employed. With its diversified industrial base, the state is a leading manufacturer of automobiles and auto components, light engineering, textiles, leather, electronic hardware, software, cement, sugar, chemicals, and petrochemicals. As a result, the state contains several hotspots for POPs and plastic pollution (Government of Tamil Nadu, Environment Department, 2017).The regulation of chemicals and wastes in Tamil Nadu is carried out under Central laws, including the Environmental Protect Act and Rules, Hazardous Waste Rules, the Air Act and Rules, the Water Act and Rules etc. (TNPCB, 2021). The state government introduced the Tamil Nadu Industrial Policy (2014) and the Tamil Nadu State Environmental Policy (2017) that look at mitigating industrial pollution. The updated Tamil Nadu Industrial Policy of 2021 also refers to the Treated Wastewater Reuse Policy 2019, which lead to the state being awarded first place under the 'Best State' category under the National Water Awards (NWAs) 2019. The following sections discuss the provisions of Tamil Nadu's Industrial and Environmental policies which relate to the regulation of chemicals and wastes.

4.6.1 Tamil Nadu Industrial Policy

The 2014 Industrial policy had the following provisions to minimise the release of toxic wastes into the environment (Government of Tamil Nadu (Environment Department), 2021; Government of Tamil Nadu (Industries Dept), 2021):

1. *Environmental Protection Infrastructure subsidy:* Dedicated Effluent Treatment Plants (ETP) and / or Hazardous Waste Treatment Storage and Disposal Facility (HWTSDF) set up by individual manufacturing units would be eligible for an Environment Protection Infrastructure subsidy. Individual Manufacturing Units adopting Zero Effluent or Wastewater Discharge, Clean Development Mechanism and Emissions Trading Mechanism will be given a higher amount of subsidy on a case-to-case basis.
2. *Provision of waste disposal facilities:* The Government will facilitate hazardous waste disposal facilities in all major Industrial parks and Special Economic Zones (SEZs).
3. *Promotion of common facilities:* The Industrial Estate Developer agencies will be encouraged to promote common ETP and Sewage Treatment Plants (STP) apart from providing a site for solid waste disposal.
4. *Green Industry Incentives:* The industries are subjected to encourage the reuse of the treated water and promote zero liquid discharge.
5. *Recycling of waste:* The government will encourage the industries for utilization of industrial space or shed for recycling, pre-processing, and other utilisation of hazardous or other waste in the existing and upcoming industrial park, estate, and industrial clusters.
6. *Incentives for R&D Projects:* The government will focus on encouraging R&D and adoption of technology in the manufacturing sector.

In addition, the policy mandates the Tamil Nadu Industrial Development Corporation (TIDCO) to facilitate various Infrastructure projects including waste treatment, handling, and disposal projects. The policy proposed commission of Petroleum, Chemicals and Petrochemicals Investment Regions (PCPIR) in Cuddalore and Nagapattinam districts.

These projects have since been approved by the Government of India. Monitoring of wastes and the implementation of relevant laws and rules concerning chemicals and waste management in these regions will be essential to prevent environmental release of POPs (IndiaChem, n.d.).

The 2021 Industrial policy builds upon the previous policy. One of its key pillars is the promotion of "industrial development that aligns with environmental sustainability". It extends the Environmental Protection subsidy to four types of solutions - Safety & Energy Efficiency Solutions, Water Conservation Solutions, Greening Solutions and Pollution Control Solutions – under the **Green Industry Incentive**. The policy also names **'Petrochemicals and Speciality Chemicals' as a sunrise sector** (Annexure II of 2021 policy). The state should make sure that monitoring and proper management of chemicals and waste is carried on in parallel to promotion of such industries.

4.6.2 Tamil Nadu Environment Policy

The Tamil Nadu State Environmental Policy (2017) proposes the following measures to ensure that the industrial development in the state is sustainable (Government of Tamil Nadu, Environment Department, 2017):

1. *Prepare Industrial Master Plans for all newly identified industrial corridors and nodes:* These plans would transparently identify areas and zones identified for industrial development and would comprehensively assess and address environmental impacts.
2. *Prepare and enforce Environmental Management Plans for existing Industrial Areas to identify and address gaps in environmental infrastructure and monitoring.* These measures will identify the Best Available Technologies and the Best Environmental Practices to tackle pollution and make provision for the creation of shared facilities for waste management (including hazardous wastes), effluent management and other environment infrastructure would be initiated.
3. *Remediate critically polluted industrial areas* as a priority in a time-bound manner.
4. *Implement Continuous and Emission Monitoring Systems* in all industrial areas. The Tamil Nadu Pollution Control Board (TNPCB) would expand the Continuous Pollution and Emission Monitoring Systems across all industrial areas in the State in a phased manner covering all industrial areas managed by SIPCOT (State Industries Promotion Corporation of Tamil Nadu), TIDCO and Small Industries Development Corporation (SIDCO) and private developers.
5. *Stringent enforcement of guidelines for conduct of Environment Impact Assessment and its compliance.*
6. *Periodic review of pollution standards and guidelines for locating industries:* Government of Tamil Nadu shall periodically review pollution norms and standards in line with National legislation, guidelines, and International best practices. The review of policy and guidelines for locating of industries and infrastructure facilities will help remove discrepancies and contradictions in existing guidelines, and incorporate best practices in environment management, factoring lessons from implementation of existing projects.
7. *Promote water recycling and re-use:* The Government of Tamil Nadu will encourage industries for implementation of the zero liquid discharge (ZLD) system, and TNPCB is the first in the country in implementing ZLD concepts in Textile and Tannery sectors. The environment-friendly technologies including recycling and reuse will be encouraged and incentivised.
8. *Environment audits:* The Government of Tamil Nadu would collaborate with the industry to evolve a system of environment audits and disclosure of environmental resource use by the industry. The objective would be to develop a comprehensive baseline of environmental resource use by industry in the State and to progressively minimise resource

intensity of industrial activity. Regular monitoring of the industrial effluents and emissions would help achieve better compliance of environmental standards.

4.6.3 Tamil Nadu Government Orders

The respective State Governments in India are empowered under the Insecticides Act, the Environment Act, and other central Acts to pass executive orders to regulate chemicals and wastes under them. The Tamil Nadu Government has passed several such orders:

- In December 2022, the state government banned six pesticides – Monocrotophos, Profenophos, Acephate, Profenophos, Cypermethrin, Chlorpyriphos-Cypermethrin and Chlorpyriphos.– for a period of 60 days. The decision was based on the toxicity of the pesticides and since their use is “likely to involve risk to human beings or animals” (Government of Tamil Nadu, 2023).
- Under a scheme for the Modernisation of TNPCB, the State Government in 2021 sanctioned the formation of flying squads (rapid inspection) in Chennai and Salem regions, and in three new offices at Manali, Ranipet and Mettur for better monitoring of Industries (Government of Tamil Nadu, 2021). This was done to increase vigilance and ensure a faster response to any violations made against the acts and rules enforced by the TNPCB.
- In February 2022, the Tamil Nadu government released the orders for appointment of Appellate Authority for pesticide licensing for authorities to manufacture/sell pesticides in their jurisdiction (Government of Tamil Nadu, 2022)
- The Government of Tamil Nadu released the order (dated 23.08.2013) for distribution of biocontrol agents/ biopesticides and sale through agricultural extension centres (Government of Tamil Nadu, 2013).

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Chapter 5
POPS ASSOCIATED WITH PLASTIC WASTE

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5.1 Interlinkages between plastics and POPs.

Attention has recently intensified towards the improper handling of plastic waste and ensuing chemical pollution, given its detrimental impacts on human health and the environment. The nexus between plastics and hazardous chemicals, such as POPs, has garnered significant concern (UNEP, 2023). Plastics inevitably intersect with POPs throughout their lifecycle. Notably, certain additives incorporated during plastic production, such as brominated flame retardants like polybrominated diphenyl ethers (PBDEs) and polyfluorinated alkyl substances (PFAS/PFOS), inadvertently contribute to POPs release (Chakraborty et al., 2022; UNEP, 2023). These chemicals are referred to as "POPs" or "additives" throughout the chapter. Additionally, during usage, plastics can act as vectors, adsorbing POPs onto their surfaces. Some additives designed to modify plastic properties are biologically active, potentially affecting the development and reproduction of living organisms (Oehlmann et al., 2009). In the environment, plastic debris break down into smaller fragments, known as microplastics and nanoplastics, raising concerns about their role as vectors of POPs in terrestrial and marine ecosystems (Cole et al., 2011; Carteny et al., 2023).

The intricate relationship between POPs used as additives in the manufacturing of plastic materials must be examined to comprehend the interplay between plastics and POPs. These compounds are pivotal in bestowing distinct properties upon the plastic matrix (Derraik, 2002). The concentrations of additives and POPs within plastic originating from the manufacturing process far exceed those garnered through external sorption, underscoring the magnitude of their influence (Moore, 2008). Researchers express concerns on the specific challenges posed by chemicals sorbed to microplastics (Gouin et al., 2011). The accumulation of plastic emerges as a prominent concern impacting surface water quality, particularly intensified by insufficient removal rates and improper disposal practices.

Plastic packaging, comprising multiple polymers and various additives, introduces additional complexities. The residues from manufacturing substances, solvents, and non-intentionally added substances (NIAS) pose challenges in waste management (Groh et al., 2019). While additives enhance polymer functionality, their documented potential to contaminate soil, air, water, and food underscores the need for prudent recycling practices to safeguard environmental and human health (Hahladakis et al., 2018). Plastic materials, particularly microplastics, are acknowledged for their capacity to adsorb and absorb POPs from the surrounding environment. Microplastics, being small particles often less than 5 mm, can arise from the fragmentation of larger plastic items or intentional addition to certain products (Thompson et al., 2004). Their high surface area-to-volume ratio renders them effective "sponges" in aquatic environments, attracting and adsorbing waterborne POPs (Groh et al., 2019). This adsorption process concentrates toxic chemicals on the microplastic surface, facilitated by the hydrophobic nature of certain plastics, like polyethylene and

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Table 5.1: Major plastic types used and corresponding applications and additives (Chakraborty et al., 2022)

Plastic Type	Uses/ Applications	Associated POPs	Major Waste Contributor
High-Density Polyethylene (HDPE)	Electrical insulation, bottles, toys	PBDEs, PFASs/, OCPs, PCDD/Fs,	Dump yard waste, E-waste, Biomedical waste, Marine litter, Industrial waste
Low-Density Polyethylene (LDPE)	Film wrap, plastic bags	OCPs, PCDD/Fs, SCCPs	Dump yard waste, E-waste, Biomedical waste, Industrial waste
Poly Vinyl Chloride (PVC)	Pipes, siding, flooring	PDBEs, PFAS/PFOS, PCDD/Fs, PCBs	Dump yard waste, Biomedical waste, Marine litter, Industrial waste
Polystyrene (PS)	Toys, cabinets, packaging	PBDEs, PFAS/PFOS, PCDD/Fs	Biomedical waste, Marine litter
Expanded Polystyrene (EPS)	Coatings for wirings, cables, construction	PBDEs, PFAS/PFOS, PCDD/Fs	Biomedical waste, Marine litter
High Impact Polystyrene (HIPS)	Toys, cabinets, packaging	PBDEs, PFAS/PFOS, PCDD/Fs	Biomedical waste, Marine litter
Polyethylene Terephthalate (PET)	Packaging, bottles, clothing	PBDEs, PCDD/Fs, PCBs	Biomedical waste, Marine litter
Polypropylene (PP)	Containers, carpet, upholstery	OCPs, PCDD/Fs, SCCPs	E-waste, Industrial waste
Acrylonitrile Butadiene Styrene	Instrument panels, dashboards,		Other plastics, E-waste
(ABS); Polycarbonate (PC) Blends	electrical appliances, mobile phone casing		

(PBDEs- Polybrominated diphenyl ethers; PFAs- Per- and polyfluoroalkyl substances; OCPs- Organochlorine pesticides; PCDD/Fs- polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans; PFOS - Perfluoro octane sulfonic acid; PCBs- polychlorinated biphenyls; SCCPs- Short-chain chlorinated paraffins)

polypropylene, which repel water. The hydrophobic similarity between POPs and these plastics enhances their affinity, facilitating interaction. Beyond adsorption, some plastic materials allow for the absorption of POPs, where these chemicals can penetrate the plastic structure and become trapped within the polymer matrix (Teuten et al., 2009). This process leads to prolonged and pervasive exposure to these toxic substances. Table 5.1 lists the major plastic types used in various applications as well as associated POPs and their primary waste stream.

5.2 Routes of exposure of nano, micro, macro, plastic-borne chemicals

Macroplastics, commonly referred to as large plastic pieces with a size exceeding 25 mm, mesoplastics refer to plastics between 5 to 25 mm, both undergo degradation, resulting in smaller particles measuring less than 5 mm (Thompson et al., 2009; Andrady, 2011). The size range for microplastics (MPs) extends from 5 mm to 1 μm, while particles smaller than 100 nm are classified as nanoparticles (NPs), as indicated by (Alimi et al., 2018). These plastics can carry various chemicals, including toxic substances, which pose potential risks to human health and the environment (Campanale et al., 2020). Understanding the routes of exposure to these plastic-borne chemicals is crucial in developing effective mitigation strategies.

Inhalation: One of the primary routes of exposure to micro and macro plastics and plastic-borne chemicals is inhalation. As plastic debris degrades over time, it can release microscopic particles and airborne chemicals into the atmosphere. People living near plastic manufacturing facilities, waste disposal sites, or areas with high plastic pollution may inhale these pollutants, potentially leading to respiratory issues and other health problems (Mupatsi and Gwenzi, 2022). Open waste burning, including plastics, releases harmful microplastics into the air. Combustion breaks down plastic materials, generating tiny particles that disperse widely. These airborne microplastics pose environmental and health risks, as they can contaminate ecosystems and potentially enter the food chain, impacting wildlife and human populations (Hess, 2023).

Ingestion: Ingestion of micro and macro plastics is another significant route of exposure to associated chemicals. The intake can occur through the oral route, involving the ingestion of MPs by consuming contaminated water, food products (such as honey and beverages), marine products within the food chain, and plants within the food chain (Enyoh et al., 2020). Additionally, direct exposure to MPs can happen when individuals ingest particles from drinking water, as noted by (Kankanige and Babel, 2020), or through the consumption of honey and sugar, as studied by (Iñiguez et al., 2017), table salt and sea food as indicated (Liebezeit and Liebezeit, 2013). Long-term exposure could lead to adverse health effects, such as hormonal disruptions and organ damage (Ali et al., 2024).

Dermal exposure: While human exposure to MPs through skin contact has not been reported yet, the skin is a major route of exposure to additives such as plasticizers and flame retardants (Li et al., 2022 and references therein). The smoke produced through combustion of e-waste is a significant exposure route for local residents (Wu et al., 2016), for instance. Dust can also constitute a source of additive as both brominated and phosphate flame retardants were reported in both outdoor and indoor environments (Zheng et al., 2017; Tokumura et al., 201).

Leaching from Plastic Products: Additives can leach from plastic products, such as food containers, bottles, and packaging (Deng et al., 2022). The chemical additives, loosely attached to the plastics, can leach out during usage or disposal. Moreover, these additives, whether linked to the plastic products or resulting from their leaching, may undergo degradation, forming other hazardous compounds that could persist in the environment and accumulate in living organisms (Peng et al., 2021). The risks associated with additives persist throughout the life cycle of plastics. Due to their challenging removal, it is highly probable that these compounds will be incorporated into newly manufactured products when plastics are recycled, as highlighted by (Wagner and Schlummer, 2020). This leaching is more pronounced when plastics are exposed to high temperatures or acidic environments (de Araújo and da Costa, 2007). As a result, humans may unknowingly consume these chemicals when using plastic products, adding to the overall exposure burden.

Comprehensive measures are required at various levels to address the issue of plastic-borne chemical exposure. These include reducing the use of materials, designing products for easy recyclability at the end of their life, enhancing recycling capabilities, exploring bio-based feedstocks, implementing strategies to curb littering, adopting green chemistry life-cycle analyses, and revising risk assessment approaches (Thompson et al., 2009). Mitigation efforts will likely be centred around plastic ban policies and public awareness campaigns.

Emphasizing the importance of life cycle assessment and circularity is crucial for evaluating the potential environmental impacts and resource consumption throughout the lifespan of a plastic product. Empowering and educating communities and citizens to minimize plastic pollution and adopt alternative options collectively is essential and should be actively promoted and enforced. The most effective results are expected to arise from collaborative efforts involving the public, industry, scientists, and policymakers (Kumar et al., 2021).

5.3 Transport of POPs from Source to Sea

5.3.1 Cycling of POPs in environmental compartments

Understanding the transport of POPs from source to sea is a complex topic requiring interdisciplinary approaches from various fields, due to the intricate properties of the substances and the diversity of sources like soil, atmosphere, riverine, vegetation, ocean currents, and point sources (Nizzetto, Grung, and Nøklebye, 2023). Although that the Stockholm Convention (SC) entered into force in 2004, and pioneering efforts on global POPs inventories were initiated (Breivik et al. 2002; Breivik et al. 2007; Lohmann et al., 2007a), high quality national data and global synthesis on the production, uses, and environmental releases of POPs are still missing (Jones, 2021; Li et al., 2023).

Even though a substantial amount of literature has been published, a global budget for the transport of POPs from sources to sea is still not yet in place (Nizzetto, Grung, and Nøklebye, 2023). Climatic changes (Gong and Wang, 2022), lack of data from primary and secondary sources (Breivik et al., 2004; Nizzetto et al.,2010; ; Li et al., 2023) make it difficult to identify the sources of POPs to the sea. Introduction of mobile, less hydrophilic, and more persistent POPs, like PFASs has also made it necessarily to reconsider the understanding of transport, fate, and behaviour in the ecosystem (Sharma et al., 2016; Eisenreich, Hornbuckle, and Jones, 2021; Muir and Miaz, 2021; Li et al., 2023) .

Biogeochemical processes in environmental compartments like air, soils, vegetation, freshwater and marine sediments, rivers, and biota, determine

Figure 5.1: A simplified picture of sources of POPs and pharmaceuticals to an urban coastal area. POPs are widely used in products used for personal care, in household chemicals, products, textiles, pesticides, and industry (Figure from NIVA).

the behaviour of POPs in the environment and their transport to the sea from primary and secondary sources. In addition, direct point sources from cities, towns, industries, wastewater treatments plants, landfills, and marine activities to coastal areas must be considered (Nizzetto, Grung, and Nøklebye, 2023). A simplified picture of sources of POPs to the sea in an urban coastal area is shown in Figure 5.1.

The complex cycling of POPs in the various environmental compartments is mainly due to their physiochemical properties like persistency towards degradation, volatility, lipophilicity, bonding to organic carbon (mobility), and bioaccumulation (Wania and MacKay, 1996).

To obtain a more holistic understanding of the behaviour and mobilization of the POPs in the global environment, in the inter-compartment exchanges between soil, air and water (through diffusion and advection), and the organic carbon/suspended solid mediated transport in water and air, mathematical multimedia models have been developed. Further information and references can be found in Nizzetto, Grung, and Nøklebye (2023).

5.3.2 Long-range transport of POPs

POPs are often divided into different categories depending on their behaviour of long-range transport (swimmers, flyers, and single/multiple hoppers) (Lohmann et al., 2007b). The properties of the contaminant largely decide the nature of the long-range transport.

Swimmers are substances that are highly soluble in water with a low volatility (dark blue area of Figure 5.2). These substances are very polar or ionic. Well-known examples are pharmaceuticals, some herbicides and short-chain PFAS (such as e.g. perfluorobutanoic acid, PFBA). Once these substances enter a water body, they follow the water current until they are either degraded or sorbed into sediment or sinking particles. Example of transport of such chemicals are provided by Brumovský et al. (2017).

Flyers are substances that are easily volatilised (high vapour pressure) (light blue area of Figure 5.2), and remain in the atmosphere, until they are degraded, for example by reaction with OH radicals. Examples of flyers are PFAS trifluoracetic acid (TFA), which are readily volatilised and deposited in the artic areas (Hartz et al., 2023). Aquatic matrices therefore do not play a major role in the transport of these chemicals.

Hoppers are a large group of substances including many POPs. Hoppers are semi-volatile and have low water solubility (high octanol-water (K_{ow}) partition coefficient) but high affinity for organic matter (most of the brown and to some extent yellow areas in Figure 5.2). The substances can undergo one or more steps of volatilisation and deposition and are transported mainly in a north-south direction due to the general wind patterns. The substances will settle in a colder climate. This is because evaporation require energy, and partition coefficients between air/water (K_{aw}, or Henry's law constant (k_H) and air/organic carbon or solids (measured as the K_{oa} (partition coefficients between octanol and air) are

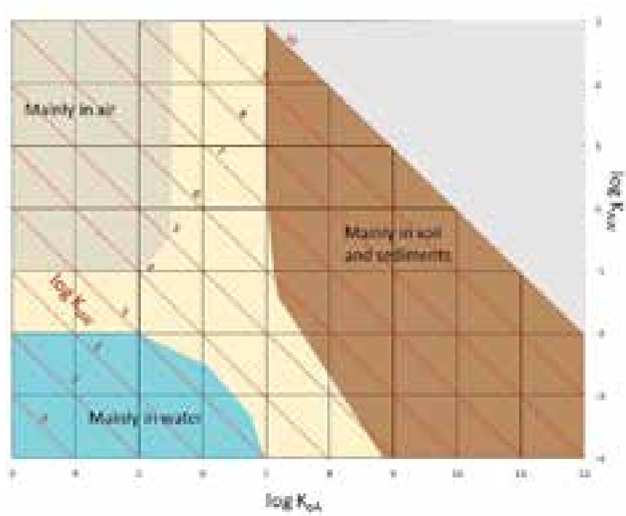

Figure 5.2: Primary environmental compartments for hypothetical substances defined by their partitioning properties log K_{aw}, log K_{oa}, and log K_{ow}. *The figure is adapted from (Wania 2003). Grey area represents values of physical-chemical properties outside the range of POPs.*

temperature- dependent (Wania and Mackay, 1993). The more volatile a compound is, the more easily and farther it travels to polar regions.

Perfluoroalkyl acids (PFAAs) enrich in sea spray aerosols in laboratory studies. Field studies demonstrated that sea spray is a potential source of PFAAs in the atmosphere (Sha et al., 2022). A correlation between PFOA and Na^+ in aerosol samples was noted from the field study conducted in two Norwegian coastal locations.

5.3.3 Rivers as the major source of POPs to sea

Wet and dry aerial depositions are prominent sources of POPs into the oceans (Dachs et al., 2002; Lohmann et al., 2007a; Galbán-Malagón et al., 2012) but it is believed that the major burden of POPs entering the sea is riverine transport (Lu et al., 2016; Nizzetto et al., 2016; Nizzetto, Grung, and Nøklebye, 2023) . The oceans play an important role as a POPs transporter and sink, determining the regional and global fate of POPs (Lohmann et al., 2007a; O'Driscoll et al., 2013). Elevated concentrations of POPs are found in coastal and deep ocean sediments (Jönsson et al., 2003; Lyu et al., 2023) marine biota (Braune et al., 2005; Fujii et al., 2007), and marine waters (Jurado et al., 2007).

River flow rates (m^3/second) vary due to the dynamic nature of rivers, responding to activities and biogeochemical processes in the catchment, which are highly influenced by precipitations and snow melt. Human activities like water abstraction, recharges and dams/reservoirs also influence the flow rate. As a result, POPs enter the rivers through soil runoff (for example pesticides from agriculture and aerial deposited POPs), urban storm water, and point discharge of effluents (primary sources from industry, sewage, wastewater treatment plans, and landfills). Fluxes (kg/year) of POPs into the sea from rivers largely depend on the flow rates and the concentrations of the contaminants. During floods and single high-flow events, significantly more contaminants get transported to the sea, compared to regular base flow (Lu et al., 2016). Riverbed sediments may also serve as a sink, where the POPs are stored until high flows cause them to be remobilized and transported into the sea.

There is limited knowledge about the riverine discharges of POPs into the seas. Monitoring of POPs in rivers is cumbersome for numerous reasons: several POPs are difficult to detect above limit of quantification (LOQ), the system is highly dynamic which requires a substantial number of samples to be analysed to capture concentration variations, and POPs analyses are very expensive. To overcome these issues, several models have been developed to predict the biogeochemical drivers in the dynamic catchment and river system. These models quantify the diffuse POPs that are being remobilized from soils and sediments and transported into the sea. Further details on such widely used models: multimedia faith models (MMFM), water quality models (WQM), and trade-offs between them, and models bridging the gap between MMFM and WQM, can be found in Nizzetto, Grung, and Nøklebye (2023).

5.3.4 Fate of POPs in the sea

The fate of POPs entering the sea depends on the physio-chemical properties of the contaminant and the exchange processes between the environmental compartments like air-water, sorption to particles and settling to sediments, remobilisation from sediments, dissolved and bioavailable for uptake by marine biota. Figure 5.3 shows the major processes determining the fate of the POPs in a marine environment. The intrinsic properties of POPs determine their partition coefficients between the environmental compartments (see Figure 5.2 and text) and this determines their fate in the marine aquatic environment.

POPs are volatile and semi-volatile and are subjected to air-water exchange. The distribution of the POPs between air and water are determined by the K_{aw}-value, where high values indicate that the substance is more likely to be found in the air compared to water, than lower values (Schwarzenbach, Gschwend, and Imboden, 2017).

In the water column, the POPs may be present as dissolved (free) or adsorbed to particles/organic carbon. The substance's affinity for adsorption to particles/organic carbon are determined by their K_{ow}, and a high K_{ow}-value means a stronger binding to particles/organic carbon. POPs bound to particle/organic carbon will move by gravity towards the bottom sediments. In the sediments, the POPs may be buried with uncontaminated suspended materials, which may remove them from further cycling into the marine environment and food web.

In the sediments, bottom dwelling organisms and turbulence from currents, propellers, and upwelling may remobilize the POPs in sediments back into the water column (Jönsson et al., 2003; Yan et al., 2008; Galbán-Malagón et al., 2012; Schwarzenbach, Gschwend, and Imboden, 2017).

The freely dissolved POPs in the water column or in sediment are bioavailable and ready for entry into the marine food web. Uptake of POPs in aquatic biota through bioaccumulation and biomagnification are of great concern. Elevated concentrations of POPs in seafood pose a threat to human health, if consumed, and POPs can negatively impact aquatic biota, resulting in both acute and chronical health consequences.

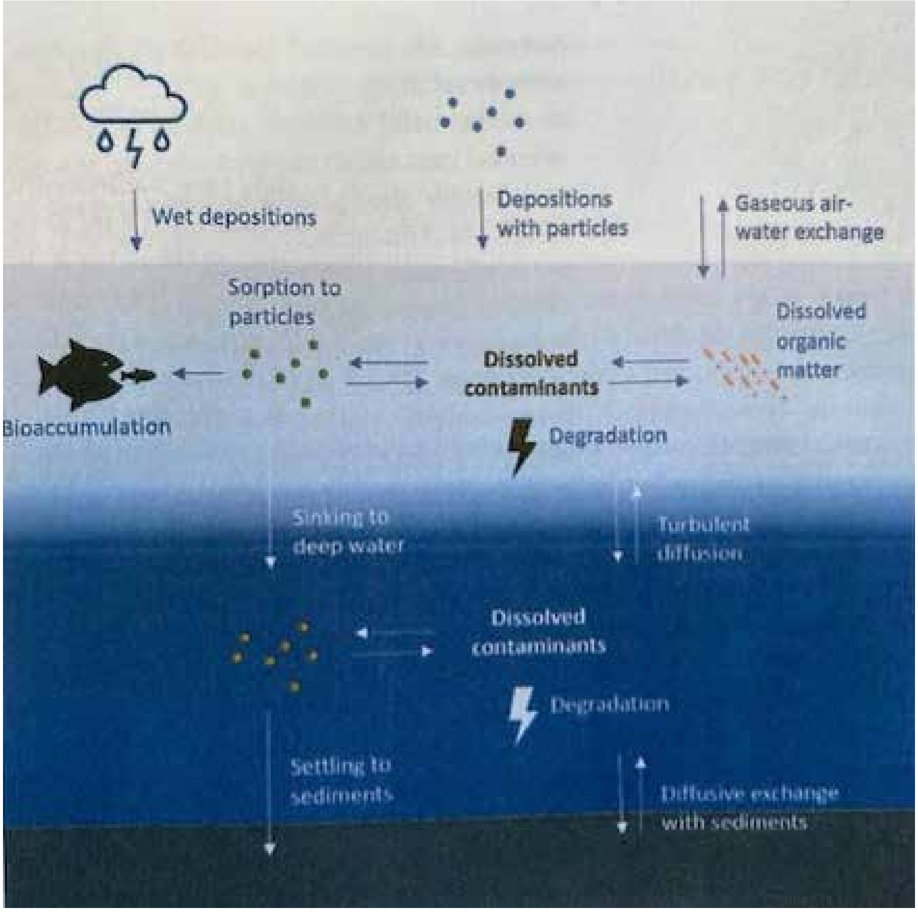

Figure 5.3: Processes determining the fate of POPs in the ocean
(Nizzetto, Grung, and Nøklebye, 2023, adapted from Jurado et al., 2007).

5.3.5 Uptake of POPs by marine biota

Aquatic organisms are exposed to substances present in seawater and sediments. Organisms higher up in the food chain are also vulnerable to POPs exposure in their food. Bioaccumulation is the net result of multiple physiological processes through ADME (absorption, distribution, metabolism, and excretion) of a contaminant due to all routes of exposure from all possible environmental compartments (air, water, soil, sediment, food and/or dermal contact with contaminated substances). In the case of POPs, the bioaccumulation can be very problematic for organisms high in the food chain. Since the bioaccumulation takes place for each step in the food chain, the concentration in organisms high in the food chain can be very much elevated compared to the lowest level (plants and primary producers). Persistence is therefore a key assessment characteristic before its released into the environment. Most substances that show biomagnification are lipophilic, and accumulate in fat tissues (Fisk, Hobson, and Norstrom, 2001). This is the case for dioxins, furans, PCBs, DDT, and a few other chemicals (Ruus, Ugland, and Skaare, 2002). On the other hand, it is observed that certain PFAS bind to proteins, and are therefore biomagnified in a slightly different manner (Conder et al., 2008) including perfluorinated carboxylates (PFCAs.

Contrary to this, bioconcentration is the net result of the uptake, distribution and elimination of a contaminant only due to *waterborne exposure* of an organism. (Leeuwen and Vermeire, 2007). Bioconcentration can be measured in lab studies. There are EU regulations on the BCF (bioconcentration factor) where a chemical is considered to be bioaccumulative (B) for BCF>2000, and very bioaccumulative (vB) for BCF>5000 [Annex XIII of (European Union Law 2023)].

Transformation of substances

Transformation processes can be divided into abiotic and biotic categories. Abiotic processes in the

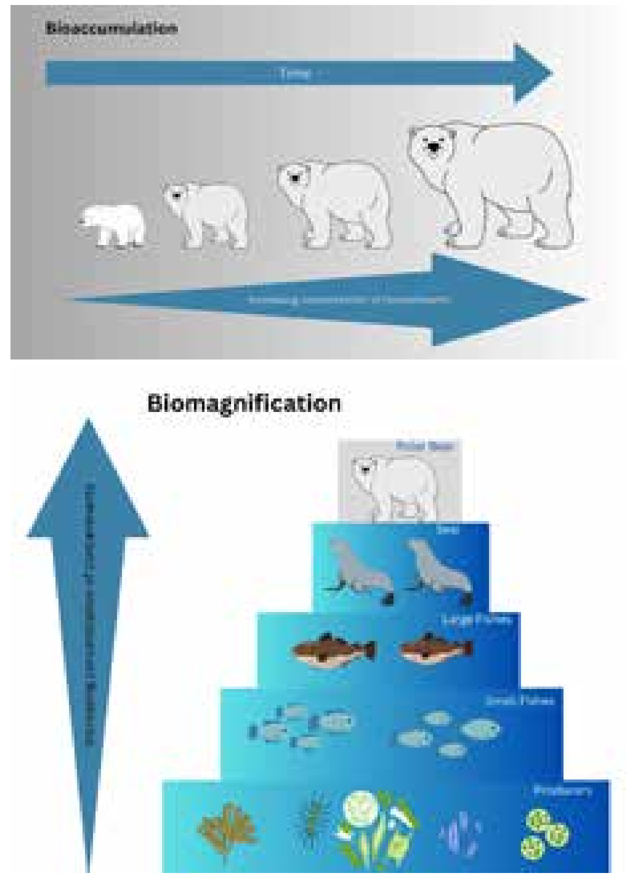

Figure 5.4: Illustration of difference between bioaccumulation and biomagnification.

water phase include hydrolysis and redox reactions. Photochemical reactions may also take place in the presence of light. Biotic processes are the metabolic processes exerted by biota on the substances. Some microorganisms can transform substances in anoxic processes. These processes are favourable for degrading persistent substances e.g. via reductive dehalogenation (Jeon et al., 2013). In general, environmental conditions such as temperature, sunlight, sediment composition and humidity, among others, may influence the transformation rates.

In contrast, higher organisms mostly utilise oxygen to transform substances. The goal of biotransformation is generally to increase the contaminant's water solubility and to excrete the transformed substance. Water soluble substances will be excreted rapidly, but lipid soluble substances will require biotransformation before they can be excreted. Insertion of an oxygen atom therefore normally is the first step in a transformation process. Often, even more water-soluble groups (often sulphates or glucuronides) are attached to the inserted oxygen in the second step, to facilitate excretion. A multitude of transformation products can be created in the process.

5.4 Production of POPs from activities related to Plastic Waste Management

Littering and leaching: The nature of POPs from dumpsite plastics varies due to the vast geographic spread of the waste sources and the type of plastic wasted. It includes a wide range of materials, including fishing equipment, agricultural plastics, bottles, bags, food packaging, taps, etc., as well as the fragmentation debris from the exposure of such materials to weathering processes like wind and water abrasion, leaching, photolytic degradation, and others (Gallo et al., 2018; Wojnowska-Baryła et al., 2022). The extensive accumulation of plastics in the oceans will undergo continual exposure to various weathering processes. Consequently, the macroplastics released today will contribute to heightened exposure to micro- and nanoplastics and their leachates in the coming decades (Arp et al., 2021).

High levels of PBDEs were found in the accumulated plastic debris near tourist beaches (Gómez et al., 2020). In India, chlorinated POPs like OCPs (organochlorine pesticides) and PCBs (polychlorinated biphenyls) were found in the surface waters due to religious congregations along the Hooghly and Brahmaputra rivers (Chakraborty et al., 2016). The use of personal care products and disposal of PET bottles were all attributed to high levels of plasticizers like phthalate acid esters in the surface waters of Hooghly and Ganga rivers (Mukhopadhyay and Chakraborty, 2021). Plastic undergoes a weathering process influenced by diverse factors, leading to fragmentation and contributing significantly to global microplastic pollution (Schnurr et al., 2018; Fadare et al., 2020). In India, mismanagement of plastic waste results in accumulation on riverbanks, causing waterway clogs and health risks through surface and groundwater contamination (Prata et al., 2019; Rodrigues et al., 2019). The inadequate disposal of plastic in landfills and water bodies exacerbates microplastic pollution, with single-use face masks emerging as a notable source (Prata et al., 2019; Rodrigues et al., 2019).

Improper plastic waste disposal in Indian landfills releases additives and POPs, posing risks to local ecosystems and human health through leachate and groundwater pathways. Recent research emphasizes the urgent need for enhanced waste management practices to mitigate the environmental impact of plastic pollution (Afrin et al., 2020; Huang et al., 2022; Shi et al., 2023).

Figure 5.5 illustrates numerous POPs that are encountered in association with plastic waste and the major waste contributing stream. Waste plastic, encountering POPs during usage, becomes a substantial source of these environmental pollutants. Leaching in dumpsites, accelerated by surfactants containing PFAS/PFOS, releases POPs with rainfall (Ham et al., 2008; Weber et al., 2011; Chakraborty et al., 2023; Sharma et al., 2024). Globally, tourist areas face plastic pollution, underscoring the need for effective waste management strategies (Kumar et al., 2021; Mihai et al., 2021; Kibria et al., 2023).

Open burning: In regions where disposal systems are lacking, the prevalent practice of open-burning plastic waste poses severe environmental and health risks. This method releases hazardous compounds such as dioxins, furans, mercury, and PCBs into the atmosphere, as documented by (Velis and Cook, 2021). Public and industrial incineration, as

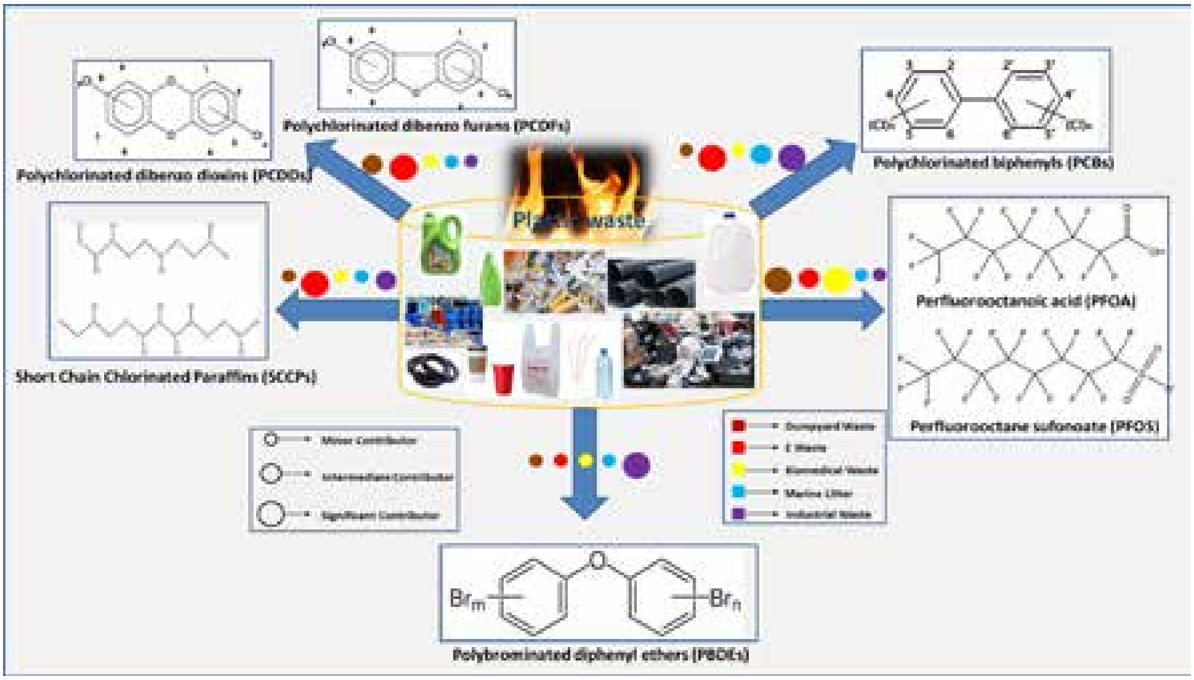

Figure 5.5: Sources of POPs in plastic waste (*Inspired from Chakraborty et al., 2022*)

highlighted in a scientific study (Yang et al., 2021), further contributes to the release of pollutants.

Burning various types of plastic can result in the formation of POPs. Notable examples include poly vinyl chloride (PVC), known for exacerbating air pollution on burning by emitting Dioxins causing cancer, reproductive and development issues, negative effects on immune system, interferes with hormons, and polystyrene, which poses risks to the central nervous system (Verma et al., 2016; Flaws et al., 2020; Senthilnathan and Philip, 2022). Globally, open burning of mixed wastes, particularly plastics like polyethylene terephthalate and polystyrene, is a significant contributor to air pollution, causing diverse environmental and human health issues (Pathak et al., 2023; Reyna-Bensusan et al., 2019).

The fate of released POPs and additives from burning plastic is critical, dispersing through air, soil, and water compartments, affecting ecosystems. Local incineration alters physical and chemical attributes, impacting nearby ecosystems. Plastiglomerates, acting as vectors, transport toxic POPs to coastal habitats, necessitating consideration in environmental management practices (Utami et al., 2023). Open burning remains common in India despite bans, releasing harmful compounds into surface water bodies (Ajay et al., 2022). Dumpsites, such as those in Kolkata (India), are significant sources of organic compounds like PCBs, Dioxins and Furans, per- and polyfluoroalkyl substances (PFASs), and short chain chlorinated paraffins (SCCPs) (Van Mourik et al., 2016; Garg et al., 2020; Rajan et al., 2021). Anthropogenic activities, like burning PVC plastic waste, contribute to POPs in dumpsite soil, impacting marine ecosystems and posing risks to human ingestion (Someya et al., 2010; Chakraborty et al., 2016; Rajan et al., 2021).

Industrial sources: In India, plastic emissions from industrial sources significantly contribute to the presence of POPs in the environment. Airborne emissions of PBDEs are associated with plastic processing, open burning at dumpsites, and informal e-waste recycling activities (Chakraborty et al., 2017). The intense burning of plastic materials during e-waste shredding releases di-ethyl hexyl phthalate, a suspected carcinogenic plasticizer, and the PCB congener PCB-126 (Chakraborty et al., 2021). Industrial waste streams, particularly those from chemical manufacturing, containing pesticides, flame retardants and surfactants, emerge as dominant contributors to POPs. Co-processing industrial plastic or pesticide waste may unintentionally generate additional POPs (Khumsaeng et al., 2013; Núñez et al., 2022). Moreover, malfunctioning combustion chambers in biomedical waste incineration facilities contribute to emissions of PCB congeners and dioxins/furans (Thacker et al., 2013; Qin et al., 2022). The impact extends to port and harbor activities, which are identified as a significant source of PCB contamination (Chakraborty et al., 2016; Gómez et al., 2020). The release of POPs from malfunctioning combustion chambers underscores the urgent need for improved industrial waste management practices and stringent emission control measures to minimize environmental contamination and associated health risks (Chakraborty et al., 2023; Venegas Montañez, 2023).

Recycling of plastics in electronic waste:
Electronic waste (e-waste) refers to the discarded electrical and electronic products that have reached the end of their useful lives. The informal methods to extract gold and other precious metals from electronic and electrical devices (like computers and cell phones) involve the handling of harmful chemicals. These chemicals can drain into waterbodies and affect the aquatic environment, causing tremendous damage to human health and affecting other environmental matrices like soil and air. In India, the informal sector recycles around 95% of all e-waste (Chakraborty et al., 2018). The escalating e-waste generation raises concerns about heightened levels of heavy metals and POPs in the environment arising from informal recycling methods. Notably, recycling printed circuit boards for metal recovery leads to the discharge of untreated waste acid leach water containing heavy metals like Pb, Cr, and Ni (Tembhare et al., 2021). Unorganised e-waste recycling is done in urban slums and suburbs in India, posing several environmental and public health concerns due to the exponential rise in both locally produced and imported e-waste. It was previously established that informal e-waste recycling activities and workshops in India release dioxins/furans and PCBs into the environment (Chakraborty et al., 2018; Chakraborty et al., 2017; Chakraborty et al., 2021). Maximum PCB contamination in the surface soil of Indian cities was observed in the informal e-waste recycling workshops engaged in precious metal recovery (88%), followed by grinding or shredding workshops (4%), dismantling sites (4%) and open dumpsites (4%) (Chakraborty et al., 2018). The study assessed PBDE levels in e-waste housing, recycled plastics, and daily-use items from recycling facilities and the market in China. The downstream life cycle noted a gradual decrease in PBDEs, emphasizing recycling's role in transferring Brominated flame retardants to a broad reuse market. Extrusion experiments mimicking e-waste plastic mechanical recycling revealed that approximately 77% of PBDEs and 39% of HBCD were retained in recycled materials, comparable to levels in products from recycling manufacturers and the consumer market (Li et al., 2020). E-waste can also contain toxic substances like heavy metals and POPs like BFRs, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), PFASs, polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs) depending on the recycling procedures employed (Ahirwar and Tripathi, 2021). In 2019, the highest volume of electronic waste (e-waste) was generated in Asia, amounting to 24.9 million metric tons (Mt). Following closely, America produced 13.1 Mt, while Europe contributed 12.1 Mt. In contrast, Africa and Oceania generated the lowest amounts of e-waste, with 2.9 Mt and 0.7 Mt, respectively (Zeng et al., 2017; Forti et al., 2020). The primary components of electronic waste included ferrous metals (37%), plastic (22%), aluminum (12%), copper (11%), and glass (7%) (Vadoudi et al., 2015). Notably,

plastics emerged as a significant constituent, constituting nearly 20% of the total e-waste. Despite ongoing technological advancements, plastic recycling in e-waste faces challenges primarily due to flame retardants (Sahajwalla and Gaikwad, 2018). Despite plastic comprising one-fourth of the total e-waste, research and efforts dedicated to e-waste plastic remain insufficient compared to metal recovery (Das et al., 2021). In India, a significant portion of electronic waste is in the informal sector, leading to unregulated recycling practices that pose serious health and environmental risks. Workers in makeshift facilities engage in hazardous methods such as open burning and acid baths, with inadequate safety measures impacting vulnerable groups like children and women (Toxics Link, 2016). Each one of these substances has been connected to harmful health outcomes, such as cancer, central nervous system impairment, and respiratory disorders (Huang et al., 2023). Workers who repair and recycle e-waste are typically from underprivileged and marginalized backgrounds, and they frequently work with vulnerable populations, including children and pregnant women (Aich et al., 2020).

5.5 Human, societal, and environmental risks associated with plastic and POPs inter linkages

Plastics are synthetic organic polymers that can be easily moulded into diverse shapes and utilized in a wide range of applications. Although invented just 110 years ago, plastics have become omnipresent and integral to various sectors of the economy, including packaging, transportation, construction, healthcare, and electronics, due to their affordability, adaptability, long-lasting nature, and impressive strength-to-weight ratio (Conesa et al., 2021). In India alone, approximately 1.7 million metric tons of plastic was produced in the fiscal year 2022 (Statista, 2024).

Though initially thought to be harmless, plastic release into the environment is now universally recognised as a major environmental burden. Plastic products, particularly single-use plastics such as polybags, sachets, and straws, do not fully degrade and remain in the environment for hundreds of years. As these are non-biodegradable and only break down little by little into microplastics and reaches different environmental matrices as it often ends up being burned, landfilled, or dumped, and hence adversely impacting all form of life.

During the production of plastics, many chemicals are used either as building monomers, additives, surfactants, and/or solvents. Such additives include fillers and plasticizers that modulate texture, colouring agents, antimicrobials, flame retardants, oil-resistance etc. that change material properties in desired ways. These additives represent 7% of the total plastic production and are essential components of plastic products (Yamashita et al., 2021). However, these chemicals leach into the environment when plastics are produced, used, and disposed of, and have profound impact on the environment and health of all living beings. The

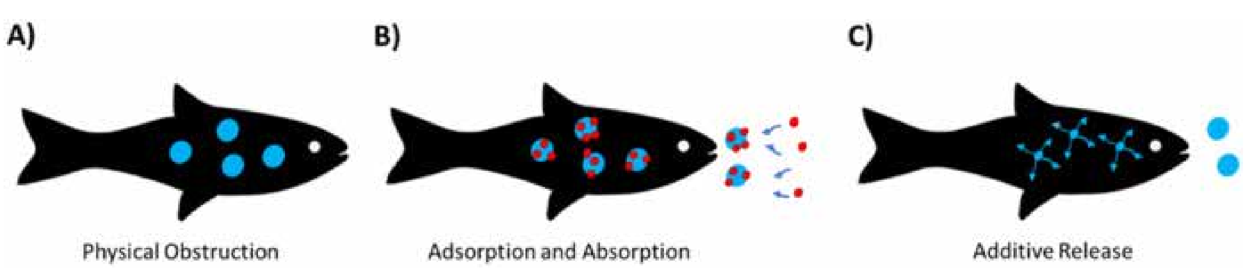

Figure 5.6: Primary methods of micro(nano)plasticecotoxicity (A) Obstruction due to physical uptake of plastic particles, (B) adsorption and absorption of chemicals in the environment and (C) release of chemical additives. (Barrick et al.,2021)

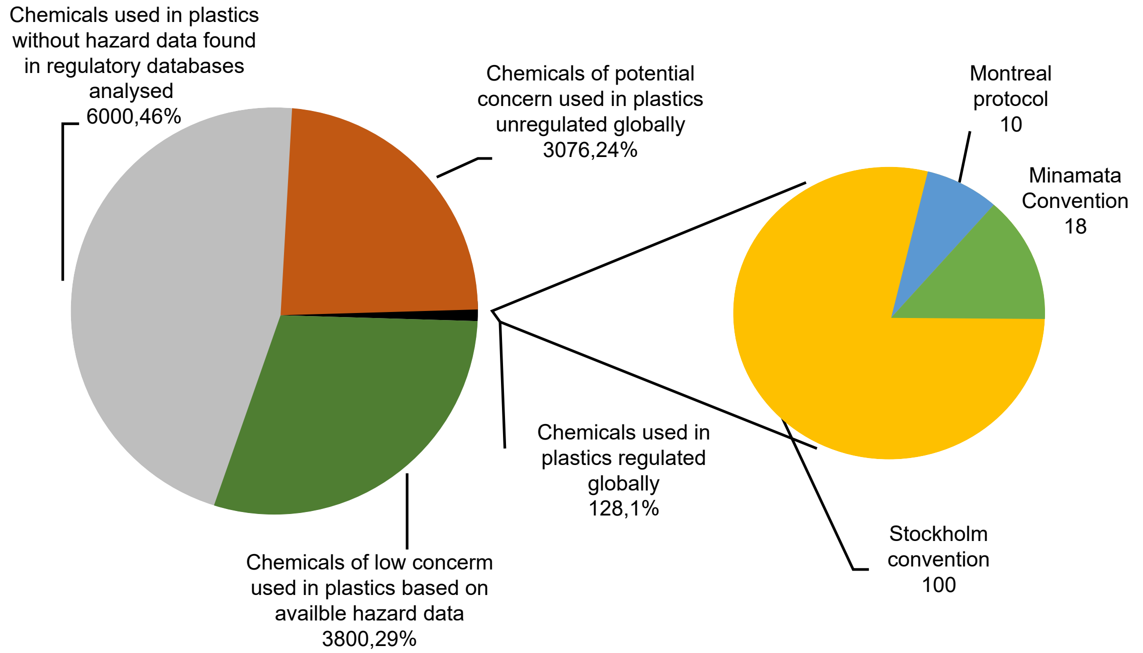

Figure 5.7: Number of chemicals of concern addressed internationally (*data extracted from supplementary material included in studies conducted by Wiesinger et al., 2021 and Aurisano et al., 2021*).

exposures can result in disruptions to reproductive systems, impaired intellectual functions, delays in physical development, cancer etc. Research suggests that people can get exposed through skin, hand-to-mouth contact, and through chemicals leaching into food and beverages (IPEN, 2022; Conesa et al., 2021).

Besides direct exposure to chemicals, most plastics, especially microplastics, have been proved to be the carrier or transporter of other harmful pollutants such as POPs (Stockholm Convention & UNEP, 2018) and heavy metals.

Pollutants are adsorbed to the surface of microplastics physically or chemically. Physical adsorption is dependent on the available surface area and weak bonding strengths (Van der Waals' forces), while chemical adsorption is mainly due to higher affinity of organic pollutants for hydrophobic surfaces of the microplastics compared to seawater (Rodrigues et al., 2018).

POPs associated with Plastics

The presence of POPs in plastic products has a negative impact not only on the environment and human health, but also on all phases of the life cycle of plastic products (IPEN, 2020). The commonly used POPs in plastics are discussed below.

1. **Flame Retardants**

   Plastics being produced from petrochemicals are highly flammable; hence to reduce their flammability and slow down the spread of fires, additives known as flame retardants are used. Flame retardants are especially important in applications where there is a high risk of fire, such as in building construction, transportation (e.g., airplanes and cars), and electrical equipment. However, many of these flame retardants have been found to be persistent and bio-accumulative and so are enlisted as POPs under Stockholm Convention.

   Some examples of flame retardants enlisted as POPs include:

a. Brominated flame retardants (BFRs): BFRs are used in foams, polystyrenes, and epoxy resins that are used to manufacture electronic casings and wire coatings (such as plastic casings for computers, TVs, and home appliances), and are commonly found in plastic children's toys. Researchers have reported that BFRs cause developmental neurotoxicity, liver toxicity, adverse impacts on neurochemicals, hepatic abnormalities, cardiovascular disorders and endocrine disruption (Cao et al., 2018; Paliya et al., 2021).

   As of 2023, five specific groups of BFRs had been listed as POPs in the Stockholm Convention: Hexabromobiphenyl (HBB), Hexabromocyclododecane (HBCDD), Octa-BDE, Penta-BDE, and DecaBDE. However, certain exemptions have been given from the listing for recycling of plastic wastes that contain some of these chemicals, hence causing exposure to consumer products made from recycled plastics.

b. Short-chained chlorinated paraffins (SCCPs): These chemicals are used as flame retardants or plasticizers in PVC (wallpaper, floor, panels, cables) & rubber, adhesives, sealants in buildings etc. Studies indicate that chlorinated paraffins adversely affect the liver, kidney, and thyroid gland in humans. SCCPs were banned in 2017 under the Stockholm Convention with specific exemptions, such as lubricant additives & plasticizer of PVC except toys and children's products. However, recycling of SCCP plastic materials risks the contamination of recycled products. The ban in SCCPs has resulted in increased uses of higher chained chlorinated paraffins (MCCPs). Considering the negative impact of the same, MCCPs is now a candidate POPs in the Stockholm Convention.

c. Dechlorane Plus (DP): Dechlorane Plus or Bis(hexachlorocyclopentadieno)cyclooctane, is a polychlorinated flame retardant designed in the late 1960s to substitute Mirex. With the global restriction of BFRs such as deca-BDE, octa-BDE, the use of DP has increased. It is used as an additive in electrical wire and cable coatings, plastic roofing materials, connectors in TV and computer monitors, etc. (Toxics Link, 2022a). It has potential for endocrine disruption and liver impairment in humans. The Stockholm Convention enlisted it as POPs to Annex A in May 2023 without any exemptions.

2. Per- and Polyfluoroalkyl Substances (PFAS):

PFAS are a family of man-made high-volume chemicals that are resistant to grease, oil, water, and heat, and are found in an extensive range of products used by consumers and industry. Being extremely persistent in the environment and in our bodies, these are also known as "forever chemicals". The PFASs can pose a risk to human health and wildlife in the long term. PFAS has been used in plastic containers and food packaging materials. PFASs are metabolism-disrupting chemicals affecting the immune systems, liver, thyroid function and some substances are classified as a human carcinogen. It also disrupts the hormone system leading to low birth weight and decreased fertility (Steenland & Winquist, 2021; Pelch et al, 2019).

Though there are nearly 5,000 types of PFAS, only three congeners so far have been enlisted as POPs in Stockholm Convention: Perfluoroctane sulfonic acid (PFOS), Perfluoroctanic acid (PFOA), and Perfluorohexane sulfonic acid (PFHxS).

3. Ultraviolet (UV) Stabilizers

Benzotriazoles (BZTs) are a class of compounds that absorb the full spectrum of UV light. UV-328 [IUPAC name: 2-(2H-Benzotriazol-2-yl)-4,6-bis(2-methylbutan-2-yl)phenol] is a predominantly used UV absorber from this class. UV-328 is added to plastics and other polymers due to its photostability to prevent discolouration and prolong product stability. It is used in the automobile sector, plastic furniture, fishing gear, etc. Because it is not bound to the polymer, UV-328 can migrate from within the polymer matrix and eventually diffuse out of the matrix and enter the environment. Studies have reported that UV328 damages the liver and kidneys in mammals and has endocrine-disrupting effects. Considering the harmful impact on environment and human health, it was enlisted as POPs in 2023 under Annex A with some exemptions (Toxics Link, 2022b).

4. **Unintentional POPs**

   Besides, there are other POPs that are present unintentionally in plastics and specially recycled plastics such as polychlorinated biphenyls (PCBs), polychlorinated naphthalenes (PCNs), dioxins & furans. The materials intended for recycling may contain intrinsic chemicals such as dyes, additives, and their degradation products that may degrade during use and/or recycling. Such chemicals may accumulate when materials are recycled several times. Even non-food grade materials may enter the recycling stream. Therefore, it is essential to monitor recycled materials for the presence of non-intentionally added substances (NIAS), including (often unknown) impurities, reaction, and breakdown products. Exposure to such migrating chemicals has been associated with chronic diseases like endocrine disruption, therefore, it is of high importance to assess the safety of recycled packaging (Marathe et al., 2021; Toxics Link, 2023a).

Plastic and POPs: Indian scenario

According to the Central Pollution Control Board (CPCB), India produced 3.4 million tonnes of plastic waste in 2019-2020. Only 30% of the plastic waste is recycled, and the rest is sent to landfills, dumped in water bodies, and to some extent, burnt along with other solid municipal waste. In India, more than 95% of the recycled plastic waste is shredded using the method of mechanical recycling. Methods like thermal recycling and chemical recycling do not have a substantial presence in the country, as they require additional infrastructure and investment. However, the quality of recyclate degrades after subsequent processes of mechanical recycling (Toxics Link, 2024; Marico Innovation Foundation, 2024).

In India app. 95% of electronic waste is handled and processed within urban slums. These procedures include manual dismantling, acid leaching, baking printed circuit boards indoor, extracting copper by burning cables, and open burning of unwanted materials outdoor. In these areas, untrained workers carry out hazardous procedures without proper personal protective gear, posing a considerable health risk to these labourers and resulting in adverse environmental consequences. Informal sector is the most exposed to plastic POPs such as BFRs, PCBs and HBCDD due to recycling activities. Research studies have emphasized the presence of atmospheric PBDEs at the site due to plastic processing, open burning in

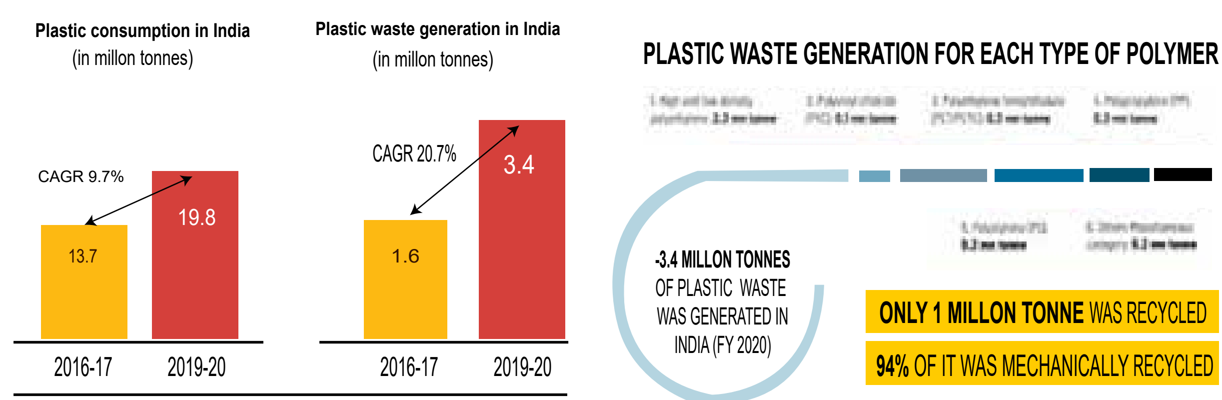

Figure 5.8 Plastic waste generation and management in India *(source: Marcio Innovation Foundation, 2024)*

dumpsites and informal e-waste recycling (Turner, 2018; Chakraborty et al., 2018).

Material supply chain contamination

Toxics Link, an India-based not-for-profit research institute, has conducted several studies and identified the possibility of cross-contamination of the material supply chain with BFRs, and gaps in the recycling processes. In 2011, Toxics Link found that 41% of the samples collected from informal units in Delhi were contaminated with BFRs (Toxics Link, 2011). All three plastic resins included in this test, namely high-impact polystyrene (HIPS), acrylonitrile-butadiene-styrene (ABS), and Polycarbonate (PC), were found to be contaminated with PBDEs (Toxics Link, 2024). A 2016 study observed that 350,000 tonnes of plastic waste were part of Waste from Electrical and Electronic Equipment (WEEE) and around 25% of that WEEE-plastic contained flame retardants. Approximately 80% of flame retardants (FR) found in WEEE were bromine-based (Toxics Link & EMPA, 2016). Another study estimated that 69,000 tonnes of BFR plastic had reached Delhi-based recyclers in 2014. The study also observed that recycling units separates FR and non-FR plastic after the grinding process. Sometimes based on the volume of FR-plastic available with them and their hands on experience on identifying it, few units separate the FR and non-FR plastic prior to the grinding as well. However, no processes were being used to remove BFR during plastic recycling or to decontaminate the plastic or prevent cross contamination in the plastic recycling units in both formal and informal sector. If the grinding unit has FR-plastic in small quantities, they mix it with the non-FR plastic. Some of the units indicated that they mix it in the ratio of around 10:1, indicating deliberate contamination (Toxics Link, 2017). Kurian et al (2019) also reported that informal waste workers deliberately mix BFRs containing plastic waste with other plastics, when the unit price is low. Thus, there was a risk of cross contamination as these recycled plastic pellets are used to manufacture new products.

Ionas *et al* (2016) reported PBDEs in 106 toys made from recycled plastics, and later determined the leaching of PBDEs from toys and exposure to children through mouthing toys. Similarly, the study done by Toxics Link and IPEN has reported high brominated flame retardants in recycled plastic toys. For the study, 25 children's plastic toys were collected from markets in India in 2015–2016. The products were screened for chemical markers of brominated flame retardants, out of which six products were found to contain the markers, suggesting that the plastic included BFRs (Toxics Link, 2023b).

A 2019-study reported alarming levels of brominated dioxins and brominated flame retardants in consumer products, such as toys and hair clips made of recycled plastics sold in Argentina, Brazil, Cambodia, Canada, the EU, India, Japan, and Nigeria. The data showed the significant levels of PBDD/Fs ranging from 5,600–386,000 pg/g and 56 – 3,800 pg WHO-TEQ/g. Researchers have revealed that these flame retardants and related chemicals, were originated largely from discarded electronics equipment, and were contaminating the recycling stream and new consumer goods made from recycled plastics (IPEN, 2019).

Similarly, a 2023-study reported brominated dioxins (PBDD/Fs) in plastic toys and other products made with recycled e-waste plastics collected from 26 countries across Africa, Asia, Europe and the Americas. The levels of PBDD/Fs found were similar to the levels found in certain hazardous wastes, including highly toxic waste incineration ash (Behnisch et al., 2023).

The toys and other plastic items made from recycled plastics contribute to BFRs exposure in children, especially in infants due to their hand-to-mouth behaviour, and through dust and chemicals present in toys. These BFRs are not covalently (strongly) bonded to the matrix and display a high potential for environmental leaching during their use, storage, disposal, as well as upcycle into newly manufactured goods.

Environmental pollution due to plastic recycling

Throughout the lifecycle (i.e., production, consumption, and disposal), plastics accumulate POPs. Plastic waste can break down into microplastics and get transported through the air, water, and soil. Over time, environmental processes lead to the leaching and release of accumulated POPs from these plastic wastes leading to their bioaccumulation and biomagnification in food chains, with food contamination being the major public health concern. Plastic processing, open burning in landfills and informal recycling can emit the adsorbed POPs hence impacting the atmospheric emission at the local or even regional level. The informal sectors do not have the facilities necessary for a closed recycling process, causing the release or leaching of POPs in recycling activities such as smelting, shredding, dedusting, acid leaching and scrubbing etc. The toxic fumes and fly ash released from incomplete combustion of plastic waste, especially e-waste at low temperatures, contained unintentional POPs including PBDEs, dioxin-like chemicals, SCCPs etc. (Lin et al., 2022). A field study at a major e-waste site in southern China reported major primary emissions due to evaporation of PCBs with possible additional emissions from recycling processes such as shredding and burning (Chen et al., 2014). Similarly, studies have reported elevated level of SCCPs, PCBs and PBDEs in air and soil matrices around dumpsites and recycling sites in India (Chaemfa et al., 2014; Hafeez et al., 2016; Chakraborty et al., 2018).

The Global E-waste Monitor 2020 project of the United Nations had estimated a total of 71 kt of BFRs in undocumented and untracked e-waste in 2019, which was largely released into the environment. If inadequately handled and disposed of in unlined landfills, these POPs may have contaminated groundwater and could have caused water and air contamination (Baldé et al., 2020; Van Yken et al., 2021). The study reported the presence of 5-10% of BFRs in printed circuit boards that on open burning released fumes of this toxic POPs (Annamalai, 2015). Reportedly, most of the municipal bodies in India either do not have suitable strategies for dealing with these e-wastes, or simply fail to implement the established policies because of inadequate infrastructure and financial resources (Awasthi et al., 2016). A 2020-study reported PCB in pond water near Kolkata city (India) due to washing of burnt e-waste residues widely used by nearby community of informal workers (Dasgupta et al., 2022). These studies represent exposure and impact in wider population.

Furthermore, it is estimated that app 10% of the total non-recyclable plastic waste is bought by local brick-makers or in cement kilns, and is used as fuel. Since the temperature at these premises is rather high, this activity may generate significant dioxin and furan emissions. Consequently, the informal sector, and its associated activities, represent a potential major POPs source (Nizzetto & Sinha, 2020). It has been observed that the optimal temperature for pellet making is often not achieved consistently (Toxics Link, 2024). This could lead to the formation of dioxins and furans.

Health Risks

No occupational and environmental safety norms were observed during the recycling processes in the unorganised sector. The informal sector is characterised by small-scale, labour-intensive, adapted technology, low-paid, unorganised/unplanned, and unregistered/unregulated work. In most cases, informal waste recycling is carried out by poor, disadvantaged, vulnerable and/or marginalised social groups, such as rural migrants, and illiterates who often resort to waste business. Mostly pregnant women, young children, and elderly people are involved in dismantling specially stripping of PVC wires. They work in close non-ventilated environment that may increase the exposure risks (Toxics Link, 2024). Within a population, neonates and children have long been recognised as the most vulnerable groups to toxicant exposures because of their multiple routes of exposure, including mother-to-child transmission during pregnancy or through breastfeeding, and hand-to-mouth behaviours. They have high metabolism rates, but immature detoxification mechanisms, which cause severe impact (Huang et al., 2023).

Current scientific data demonstrate the impact of exposure to plastic associated chemical additives. Polymers, once present in the environment, have the potential to concentrate POPs. Unintentional ingestion of indoor dust contaminated with POPs through plastic products has been identified as a major potential exposure pathway for humans, along with dietary and inhalation routes (Harrad et al., 2016; Gao et al., 2018). Research studies have indicated that individuals employed at plastic recycling facilities and those living nearby may be exposed to hazardous chemicals by inhaling toxic dust or fumes produced during the recycling process. This puts their right to health at risk, as prolonged exposure to air pollution heightens the probability of these workers and residents developing persistent health issues, including cancer and reproductive system disorders (Human Rights Watch, 2024).

A study reported high levels of PCBs in human breast milk (43–890 ng/g) in the population living around the dumpsite of Kolkata (Someya et al., 2010). Similarly, PBDEs and HBCDs were also detected in human breast milk samples collected from various locations across the country (Devanathan et al., 2012). The studies have established that involvement of pregnant women in e-waste recycling activities contributed to the elevated PBDEs concentrations in umbilical cord blood samples (Li et al., 2018). Similarly, reports indicate the presence of PFOA (median 16.95 ng/mL) and Dechlorane plus (ranging from 7.8 to 465 ng/g) in maternal serum samples collected from e-waste recycling sites (Wu et al., 2012; Huang et al., 2023).

Microplastics

Microplastic pollution, especially in the marine ecosystem has become one of the world's main environmental concerns. Microplastics in the marine environment can infiltrate the biological systems of a diverse array of organisms, spanning from herbivores and secondary consumers to predators at higher trophic levels, including microorganisms, plankton, benthic invertebrates, fish, deep-sea biota, and larger mammals. This ingestion can lead to detrimental effects such as neurotoxicity and genotoxicity, as well as diminished feeding, filtration, survival, and reproductive capabilities. Consequently, these impacts contribute to a decline in both the quantity and quality of the food supply for humans and other aquatic organisms (Naidu et al., 2018; Savoca et al., 2019; Wang et al., 2020).

Microplastics acts as carrier of organic pollutants due to their greater affinity, hence capable of transporting contaminants to the ecosystem via the food chain. Human exposure to PBDEs and HBCDs occur mainly via diet and, particularly, through fish and fish oil-based products (EFSA, 2021). In addition, they can also increase their environmental persistence (Alfaro-Núñez et al., 2022; Zhang et al., 2020). Pittura et al., (2022) reported microplastics and brominated flame retardants in freshwater fishes from Italian lakes. The fish species from Lake Piediluco exhibited a more elevated percentage of organisms positive to MPs ingestion (45%) and the higher levels of PBDEs and HBCDs were found as 343 and 792 pg/g, respectively in *Perca fluviatilis* (European perch); and 445 and 677 pg/g, respectively in *Rutilus rutilus* (common roach).

Turner (2022) had estimated that the input of PBDEs to the ocean when "bound" to marine plastics and microplastics ranges from about 360 to 950 tonnes per year, based on the annual production of plastics and PBDEs over the past decade (process illustrated in Figure 5.9).

Microplastics adsorbed UV-328 have been found in the tissues of seabirds (Tanaka et al., 2020; Yamashita et al., 2021). Jayasiri et al., 2015 have reported adsorbed PCB, HCH and DDT in microplastics collected from Mumbai beach (India). Yeo et al (2020)

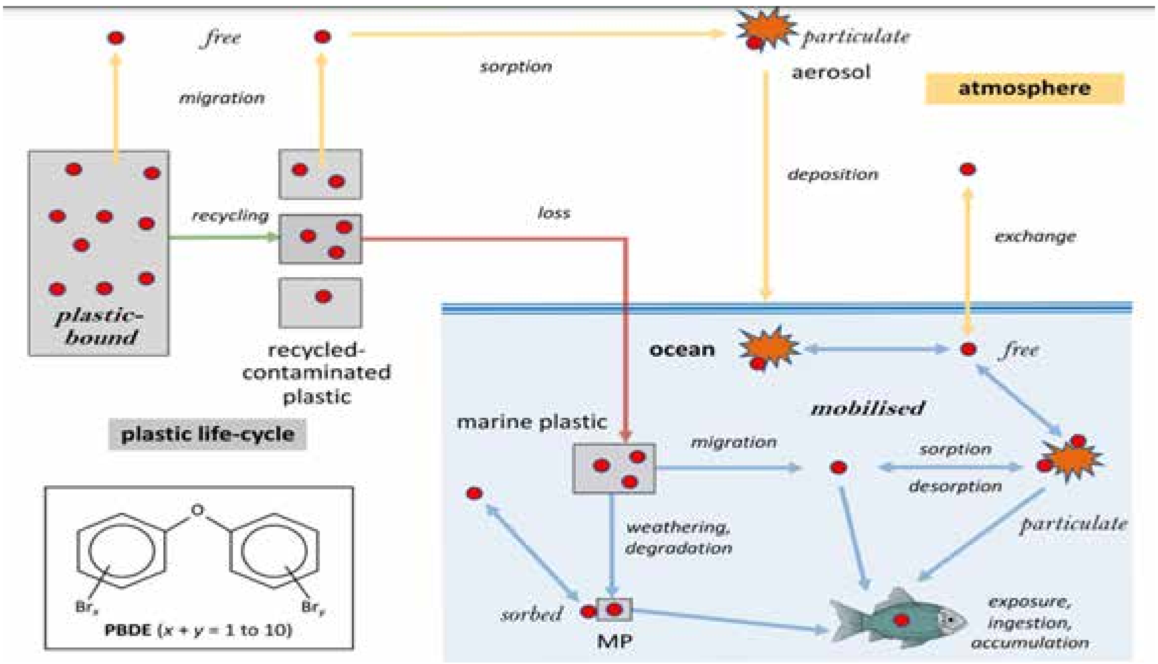

Figure 5.9: Fate and Behavior of plastic-bound PBDEs *(Red dots represent PBDE molecules that can be encountered in plastics (in grey boxes and "bound"), or occur as free or sorbed molecules that have migrated into the environment (mobilised) and are free or are sorbed to aerosols and particulate matter (orange stars) or microplastics (MPs)). Source: Turner, 2022*

reported PCBs and PBDEs in microplastic particles and zooplankton in open water in the Pacific Ocean and around the coast of Japan. Similarly, PCDD/Fs, PBDD/Fs, and PBDEs on the MPs had been reported in the samples collected from other beaches (Chiu et al., 2020; Wang et al., 2021). Recycling of electronic waste and poor management of ship-breaking activities were suggested as potential sources of PCBs in India (Jayasiri et al., 2015). Besides, coastal cities, ports, shipping activities, coastal landfills and coastal dumping sites were also identified as important sources of plastic pollution in oceanic environments (Galloway et al., 2017).

5.5.1 Workers and communities particularly vulnerable to POPs exposure associated with plastics

In the Global South, around 2.7 billion people lack access to waste collection, whilst around 40% of collected municipal solid waste is estimated to be inadequately managed by open dumping and burning (Wilson, 2023). This causes significant environmental and health risks to workers and nearby communities, and contributes to exacerbating broader interlinked sustainability challenges of climate change, biodiversity loss, and pollution.

Mismanaged waste and pollution often have a profound impact on workers, especially due to the presence of harmful chemicals in plastics, such as phthalates, bisphenol A (BPA), lead, PFAS, and PBDEs. These substances have been linked to serious health issues like cancer, birth defects, and disruptions to the immune, endocrine, and reproductive systems (Flaws et al., 2020). Workers face an elevated risk because they are exposed to higher concentrations of these chemicals over extended periods. It is worth noting that diseases stemming from such exposures are often diagnosed many years later, and are not often accounted for in global disease burden assessments.

Workers in various industries encounter plastics throughout their daily activities, spanning the entire lifecycle of plastics, from production to disposal. Those in the informal economy face a heightened vulnerability to the hazardous chemicals associated with plastics. This is because they operate in environments with limited occupational safety and health regulations, and minimal social protection measures. Waste pickers and informal recyclers who handle plastics at the end-of-life stage are particularly at risk. They come into direct contact with waste and recyclables during tasks like collection, sorting, washing, heating, and melting of plastics. Additionally, waste pickers are exposed to health hazards when waste is openly burned in landfills, as they inhale contaminated air, come into contact with polluted soil and water, and may ingest contaminated food. Evidence indicates that female waste pickers are especially susceptible to health risks associated with plastics, which can include adverse effects on their reproductive health due to exposure to endocrine-disrupting chemicals.

Because of their physiological and biological makeup, social roles, cultural standards, and the nature of jobs that expose them to more care and cleaning products, women are more likely than males to be exposed to chemicals, including those found in plastics, and to have several health impacts.

Vulnerability depends on the time of exposure to chemicals, but is highest during in-utero, childhood, youth, pregnancy, lactation and menopause stages. If women come in contact with toxic substances during pregnancy or breastfeeding, evidence suggest that negative health impacts can be passed on to the child (Arora et al., 2023). As such, it is indicated that microplastics can be transported through the placenta (Lynn, Rech & Samwel, 2017). Estrogenic EDCs is linked to ovarian disfunction, fibroids in the uterus and reduced fertility of women. Bisphenol A exposure can reduce the egg quality and have a negative impact on fertility treatment for women (Gore et al., 2014).

Cultural and social norms can affect women's and girls' exposure to chemicals. In most countries, women are still expected to do most of the household cleaning activities. As a result, they are more prone to get in contact with harmful substances (including microplastics) that can leach out during cleaning. For example, a number of chemical additives like stabilizers and plasticizers are contained in PVC flooring and can be released (Lynn, Rech & Samwel, 2017). Similarly, the usage of personal care and cosmetic products, which contain about 13.000 chemicals, can be harmful; only 10% of these products have been tested. Skin whiteners and hair products are popular among women of colour, that frequently consist of toxic ingredients making them more vulnerable to a high-level exposure (Zota & Shamasunder, 2017). Endocrine Disrupting Chemicals (EDCs) are also found in personal care and cosmetic products (PCCPs) that are mostly used by women; intentionally added microplastics in PCCPs are identified in toothpaste, shampoos and baby care products (Lynn, Rech & Samwel, 2017).

Due to prevalent gender roles, women can be disproportionately affected by chemicals in their workplace. In some countries, the plastics manufacturing has many more female than male workers. While in the US, almost one third of employees in the sector are women, Canada even tops that number – with over three thirds of their workers being women. Many EDCs are used in the plastic industry, leading to high rates of breast cancer among the women processing plastics, manufacturing plastic products and working with rubber or synthetic textile fibres (Dematteo et al., 2012). Because plastics contain hazardous chemicals like flame retardants, heavy metals and plasticizers (IPEN, 2017), plastic recycling exposes workers to a unique kind of chemical exposure (Stenmarck et al., 2017; Strakova et al., 2018).

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Chapter 6
ENVIRONMENTAL MONITORING TECHNIQUES OF TARGETED POPS

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6.1 Sampling in the aquatic environment

The objective of monitoring persistent organic pollutants (POPs) in a waterbody is to establish an overview of status to protect the environment and human health and to reduce pollution and take measures if needed.

Analyses of POPs are expensive, and to establish an effective and targeted monitoring program, information about activities in the catchment that may pollute the water body is of importance. Data on discharges of POPs from industry, landfills, wastewater treatment plants, runoff from agriculture, and riverine transport of upstream contaminants are crucial. Knowledge about industrial production and processes, agricultural cultivation, the type of waste deposited in the landfill, and wastewater treatment processes may provide information about major and potential POPs of concern. If fluxes of POPs to the waterbody can be calculated or estimated and routes of entry into the waterbody are known, the design of a monitoring programme will be optimised.

Monitoring stations and selection of POPs

Areas where the effluent water of concern may impact the water body should be considered when establishing monitoring stations. Often, monitoring stations are placed in a transect that extends further from the source. Current and water flow and information about how the discharged water will mix in the waterbody determine the location of the monitoring stations. To provide knowledge about potential sources upstream, monitoring programs often include reference stations unaffected by the discharge point of concern.

Contamination of samples during sampling

Suitable containers for the samples should be available before proceeding on a field sampling excursion. Special care needs to be taken so that the containers do not contaminate the sample (e.g., burnt glass containers for sediment sampling, proper plastic bottles for sampling of PFAS in water, and burnt large glass bottles (1L or more) for water samples of hydrophobic POPs). During sampling, care should be taken to not contaminate the sample. Use of personal care products, textiles, smoking, and use of contaminated plastic or metal equipment can potentially contaminate samples. If several different analyses are required to be performed on a single sample, there is a need to ensure thorough mixing and subsequent splitting of the sample under clean conditions. For instance, when measuring pH, conductivity, and other field parameters in the water sample, it's important to split the sample and ensure that the POPs sample doesn't come into contact with the other measurement equipment.

Matrices

Monitoring of POPs is performed in water, sediment, and/or biota. The selection of matrices is tightly connected to the property of the POP. Chemical properties like octanol and water partition coefficient (K_{ow}[1]) and bioconcentration factor

1 K_{ow} indicates the hydrophobicity of a chemical substance, increasing hydrophobicity with increasing K_{ow}. K_{ow} (both experimental and predicted) can be found at https://comptox.epa.gov/dashboard/

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Table 6.1: Examples of preferred matrices for monitoring of POPs and other organic substances. Guidance Document No. 25 (European Union, 2010).

Substance	BCF	Log K_{ow}	Water	Sediment	Biota
PCB	~ 25,000	~ 6	No	Yes	Yes
Pentachlorobenzene	1,100-260,000	~ 5	No	Yes	Yes
Hexabromocyclododecane	~ 41,540	~ 7.5	No	Yes	Yes
Atrazine	~ 10	~ 2.5	Yes	No	No
Bisphenol A	~ 70	~ 3.4	Optional	Optional	No

(BCF[2]) determine if the sampling should consist of samples of water, sediment, and/or biota. According to Guidance Document No. 25 (European Union, 2010), compounds with a log K_{ow} >5 should preferably be measured in sediments or in suspended particulate matter (SPM), while compounds with a log K_{ow} <3 should preferably be measured in water. For compounds with a log K_{ow} between 3 and 5, sediment or SPM is optional. Monitoring in biota should be performed when the BCF is >100. Recommended sampling matrices for some Stockholm Convention POPs and other contaminants are shown in Table 6.1.

Sampling techniques

Water

Since several of the POPs are often very hydrophobic, low concentrations are expected in the water phase, and sediment and biota are generally more preferred matrices for sampling.

If sampling in water is advisable, grab sampling is often performed, simply by dipping a suitable bottle in the water body. A composite sample may also be collected by combining multiple grab samples collected at specific times or locations. When sampling in different water depths is preferred, a variety of water sampling devices exist on the market (Figure 6.1).

2 BCF is the ratio of the concentration of a substance in an organism to the concentration in water. BCF (both experimental and predicted) can be found at https://comptox.epa.gov/dashboard/

Sampling should be representative and performed according to the intention of the monitoring program. Water samples of POPs are usually not filtered (0.45 μm), since the filtering will remove a substantial part of the POPs associated with suspended material. Post sampling, bottles should be placed in a cold and dark place and frozen immediately until further processing.

In rivers, sampling should be done in running water. In lakes, the outlet may be used, or sampling may be performed at different depths at certain locations in the water body. Very often, a composite sample is collected from different depths. If a point source in a river or lake should be analysed, sampling stations should be adopted for the purpose of the monitoring campaign.

Water sampling of POPs in marine water bodies requires caution because current and tide are likely to dilute and spread the POPs of concern. ISO 5667-1 (2023) provides a general guide for water sampling. Strategies for surface water monitoring of POPs according to the EU Water Framework Directive are provided in Guidance Document No. 19 (European Commission, 2009).

Sediment

Sampling of sediment is a preferred matrix for several of the POPs due to the hydrophobic nature of many contaminants. Several different sampling equipments are available for sampling of sediments. Equipment like grabs/dredges and corers is widely

Figure 6.1: Handhold Limnos and Ruttner water sampler for 0-70 m depth and a telescopic sampling device for bottle sampling (from left to right). Republished with permission from KC-Denmark.

used (Figure 6.2). In some cases, like sampling of floodplains or riverbanks, shovels, spades, and augers may be used. The selection of sampling stations for sediments should be linked to the monitoring program's purpose. In rivers, it is important to remember that floods and fluxes upstream may result in rapid changes in the concentrations of POPs in the sediments. In lakes and marine water bodies, the deepest parts will be an accumulation area for sediments. Sedimentation rates (mm/year) may vary considerably between water bodies (Zhang & Xu 2023; Harter & Mitsch 2003). In tropical areas, the biomass production is generally much higher than in temperate climates, and the sedimentation rates are then much higher in tropical climates. Supporting parameters like total organic carbon (TOC) and grain size distribution (sand, silt, and clay) are often analysed in sediments to determine texture and to provide information about mode of transport and deposition.

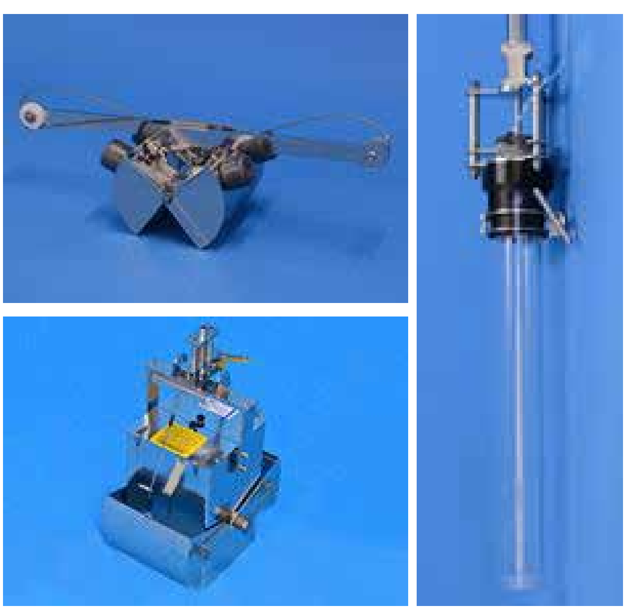


Figure 6.2: Handhold VanVeen (on the top) and Ekman grabs and Kajak corer used for sediment sampling (from left to right). With permission from KC-Denmark.

A general guide for sampling of sediments is described in ISO 5667-1 (2023) and in the (European Commission, 2010).

Biota

Biota is widely used for monitoring POPs in the aquatic environment (European Commission, 2010). The aquatic ecosystem is monitored to safeguard it from harmful chemicals and human health risks posed by the consumption of contaminated food originating from the aquatic environment. Different types of biota are used for monitoring, but top predators in the aquatic ecosystem are preferred since the POPs tend to accumulate in the food chain. Wild caught fish (Figure 6.3.) is the favoured organism used, but bivalve and prawns are also used. When selecting biota, the species should be widespread and abundant throughout the year, relatively sedentary (reflecting local contamination), lived long enough for bioaccumulation to occur, and of large enough size to yield enough tissue for analysis. Muscle is a tissue that is frequently used for monitoring POPs, but liver, blood, eggs, and kidney

Figure 6.3: Fish from India used for food consumption, which may be used for analyses of POPs.

may also be used. Supporting information about the biota like age, length, dry weight, and fat content is usually added, which makes it easier to interpret the data and compare results.

Sampling frequencies

Repeated sampling of POPs is necessary to capture variations in the environmental concentration.

A grab sample of water provides a snapshot of the water's quality at the precise time and place of collection. Concentrations of POPs in water may vary considerably, for example, in the rainy season compared to the dry season. During the rainy season, point sources from industry and wastewater treatment plants may be more diluted due to higher flow in the river.

Sampling frequencies of POPs in sediments should be adapted to site-specific areas and the purpose of the sampling campaign. In general, concentrations of POPs in river sediments vary considerably due to washout, floods, and depositions from upstream. In deep basins in lakes and seawater, sedimentation rate may be minor, and low sampling frequencies are often justifiable. In lakes with a high production of biomasses, the sedimentation rate will be higher than in lakes with low production of biomasses.

In biota, sampling frequencies are usually less frequent since it typically takes time for biota to accumulate POPs. Sampling frequencies for POPs may in general be weekly to monthly for water and yearly for sediments and biota.

Data handling

To protect the aquatic ecosystem, the measurements of concentrations of POPs in all matrices may be compared with national permissible limit values/environmental quality standards. Measured concentrations for biota can be evaluated in relation to national human food consumption advice, and similarly, this can be done for water if it is used without any treatment and as potable water. Comparing measured concentrations with other studies is also of interest, whether the results are nationally or internationally originated.

When analysing POPs, it is important that the laboratory delivers chemical analyses of good quality. When possible, the laboratory's limit of quantification (LOQ) should be lower than the limit values/environmental quality standards and permissible level for consumption.

When reporting data from the analysis of several samples at the same location, caution is necessary. Concentrations of contaminants in environmental matrices are seldom normally distributed but often have a log-normal distribution. Therefore, caution must be exercised when reporting environmental concentrations. Reporting median concentrations rather than mean concentrations is often appropriate since median concentrations are only minimally affected by the magnitude of any single observation. See chapter 1 of (Helsel & Hirsch, 1993) for more information.

Sampling of air, soil, and biological material

Sampling techniques for the targeted POPs in different matrices are briefly summarised below.

Atmosphere: Two methods commonly employed for the sampling of POPs in air are active sampling and passive sampling (Figures 6.4 and 6.5). Active air sampling, a conventional method utilised in monitoring programmes (Xu et al., 2013), is complemented by passive air samplers (PAS), which come in various designs, dimensions, and forms. Passive sampling relies on either permeation

Figure 6.4: Typical high volume air sampler
Figures taken from Chandra et al. (2024)

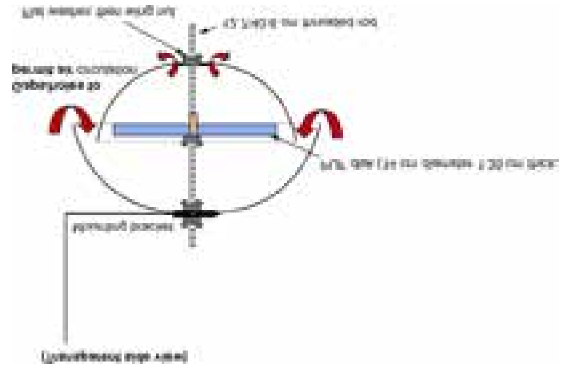


Figure 6.5: Typical passive air sampler.
Figures taken from Chandra et al. (2024)

or diffusion, utilising mediums such as solvents, polymer resins, chemical reagents, or porous adsorbents (Bohlin et al., 2007). Polyurethane foam disc-based passive air samplers (PUF-PAS) have been extensively used in India for monitoring POPs, including OCPs (Chakraborty et al., 2010), PCBs, and PBDEs (Chakraborty et al., 2017a; Chakraborty et al., 2010), have standardised time-integrated PUF-PAS against an active sampler for organochlorine compounds with a sampling rate of 3.5 m^3/day. (Abdallah et al., 2008) employed PUF-PAS for collecting indoor air samples in the UK for hexabromocyclododecanes (HBCDs) analysis, while low-volume active air samples were used for outdoor air sampling. In China, Chen et al., (2020) utilised a $PM_{2.5}$ sampler for sampling six target polychlorinated pollutants, including hexachlorobutadiene and pentachlorobenzene (PeCB), each taken over 24 hours with a flow rate of 100 L/min and a Whatman quartz microfibre filter.

Passive sampling was conducted using PUF-PAS discs pre-cleaned through various methods, such as Soxhlet extraction with acetone and diethyl ether (Navarro et al., 2019), pre-extraction with n-hexane and acetone (Fang et al., 2017), and pre-cleaning with acetone and DCM (Pegoraro & Wannaz, 2019).

Soil: A variety of equipment is used for soil sampling, but soil augers or probes are most often used, but in some cases a garden spade or shovel may also be used (Figure 6.6). In the French West Indies, Cabidoche et al., (2009) utilised a borehole sampler (0–30 cm depth) to collect composite soil samples for the determination of chlorpyrifos. Meanwhile, Halse et al., (2015) employed a stainless-steel hand-held corer to gather composite soil samples (0–5 cm) from Northwestern Europe for PeCB analysis. Xu et al., (2013) emphasised the importance of storing all samples at -20°C before analysis.

Figure 6.6: Soil auger for soil sampling (0-10 cm) (photo: NIVA) and scoop for soil sampling (Chandra et al., 2024).

Biota: Various different biological samples such as human breast milk, cow/buffalo milk, blood, eggs, and other edible products are often collected to monitor exposure of humans to POPs (Food safety: Persistent organic pollutants (POPs)) (who.int).

Chemical analyses of POPs

Analysing trace amounts of organic pollutants in environmental samples poses a significant challenge due to the intricate and varied nature of sample matrices. Matrix interferences can adversely affect parameters such as limit of detection (LOD), limit of quantification (LOQ), linearity, accuracy, and precision in analysis (Gaonkar et al., 2021). In analytical chemistry, selecting appropriate extraction, preparation, and instrumental techniques is crucial to ensure the method's suitability and to meet necessary data quality objectives (Bethem et al., 2003). Given the ultratrace levels of organic pollutants and the complexity of environmental matrices, proper sample preparation is essential. Techniques such as Soxhlet, pressurised liquid extraction (PLE), supercritical fluid extraction (SFE), matrix solid-phase dispersion (MSPD), microwave-assisted extraction (MAE), ultrasonic-assisted extraction (UAE), Liquid–Liquid–Extraction (LLE), solid-phase extraction (SPE), and solid-phase microextraction (SPME) are commonly employed for extraction and liquid and gas chromatography coupled with Mass Spectrometry (MS) is used for quantification of the targeted pollutants (Pavithra et al., 2023). This chapter provides a comprehensive overview of various sample preparation procedures developed for the selective and sensitive analysis of targeted persistent organic pollutants (POPs) in diverse environmental matrices.

6.2 Extraction and clean-up methods

The extraction techniques for the POPs in different matrices are summarised below and listed in 6.2.

A. Surface water: To date, the extraction of persistent organic pollutants (POPs) from surface water has commonly involved methods such as liquid-liquid extraction, solid-phase extraction, and solid extraction discs. Notably, solid-phase extraction (SPE) stands out as the most extensively employed technique for both enriching and purifying the water samples. Daso et al., (2013) extracted the samples using liquid-liquid extraction for the analysis of PBDEs, followed by a clean-up procedure with a pasteur pipette containing different forms of silica gel. HBCD was also extracted from water samples by liquid-liquid extraction using hexane, followed by a multi-layered silica gel clean-up (Zhang et al., 2018). Ichihara et al., (2014) performed the extraction of surface water samples for hexabromocyclododecane (HBCD) analysis using a solid extraction disc and a glass fibre filter. The method involved utilising a Soxhlet device for extraction and subsequent concentration with a rotary evaporator. The eluate underwent purification by being introduced to solid-phase extraction cartridges containing 500 mg of previously cleaned graphite.

B. Atmosphere: For the analysis of hexabromocyclododecanes (HBCDs), PUF discs and filters underwent extraction via Soxhlet extraction with hexane/dichloromethane (DCM) for 8 hours. Subsequently, the extracts underwent a cleanup process using SPE cartridges filled with 8 g of pre-cleaned acidified silica, as described by Abdallah et al., (2008). In the study conducted by Hao et al., (2019) for polybrominated diphenyl ethers (PBDEs) analysis using the revised U.S. EPA method 1614, air samples were subjected to soxhlet extraction for 24 hours. The cleanup of the extract was accomplished through a pre-cleaned acid/basic silica gel column, with hexane serving as the eluting solvent. Pegoraro & Wannaz, (2019) utilised accelerated solvent extraction (ASE) for the extraction of PUF disc samples for PBDEs and OCP analysis. The subsequent extracts underwent a cleanup process employing an activated alumina-silica column.

C. Soil and sediment: To recover chlorpyrifos (CLS) from the soil sample, pressurised liquid extraction (PLE) was employed. The resulting extract underwent reduction through a nitrogen stream and was concluded with the addition of 1 ml of cyclohexane, as detailed by Bristeau et al., (2014). For the extraction of pentachlorobenzene (PeCB) from soil samples, an Accelerated Solvent Extractor (ASE) was utilised, followed by fractionation with a silica column, according to the procedure outlined by Halse et al., (2015). The extraction of soil and sediment samples involved Soxhlet extraction, followed by alumina/silica column cleanup, following the methodology presented in Chakraborty et al., (2015). The resulting extract was concentrated using a rotary evaporator and further reduced with nitrogen.

D. Biota: For the biota samples, for extraction of PCBs, PBDEs, DDTs, and HCHs, entire fresh fish muscle (0.2–6.2 g) and invertebrates (0.1–4.1 g) were homogenised using anhydrous Na_2SO_4. The homogenised samples were then spiked with internal standards (CB 143, BDE 77, ε-HCH) and subjected to a 2-hour extraction process using a hot Soxhlet apparatus with 100 ml hexane/acetone (3/1, v/v). Following lipid determination, the extracted material underwent a cleanup procedure on 8 g acidified silica, and the analytes were subsequently eluted with 20 ml hexane and 15 ml dichloromethane. The purified extract was concentrated and reconstituted in 100 μL iso-octane (Verhaert et al., 2013).

6.3 Instrumental Analysis

Analytical techniques for the assessment of emerging persistent organic pollutants (POPs) have been developed, employing various instruments such as Gas Chromatography Tandem Mass Spectrometry (GC-MS/MS), Liquid Chromatography Tandem Mass Spectrometry (LC-MS/MS), and Gas Chromatography Electron Capture Detector (GC-ECD). Liquid Chromatography (LC) and related atmospheric ionisation methods, such as electrospray ionization (ESI), are commonly applied for the analysis of non-volatile and thermally labile

Table 6.2: Extraction techniques for the targeted POPs.

Analyte	Matrix	Internal standard/ Surrogate standard	Extraction method	Clean-up	Reference
HBCD	Water	$^{13}C_{12}$-labeled α, β-, and γ-HBCD	SPE	multi-layer silica gel column	(Oh et al., 2014)
PBDEs and BB	Water	BDE and BB	LLE	multi-layer silica gel column	(Daso et al., 2013)
OCPs	Water	2,4,5,6-tetrachloro-*m*-xylene (TCmX)	SPE	alumina/silica column	(Rex & Chakraborty, 2022)
PCBs	Water	PCBs, and PCB– 209	SPE	alumina/silica column	(Rex & Chakraborty, 2022)
PCDD/DFs	Water	$^{3}C_{12}$-labelled PCDD/DFs	accelerated solvent extraction system	basic alumina column	(Nie et al., 2013)

Analyte	Matrix	Internal standard/ Surrogate standard	Extraction method	Clean-up	Reference
PBDEs	Air	^{13}C- PBDES	Soxhlet Extraction	acid/basic silica gel column	(Hao et al., 2019)
PBDEs	Air	Mirex	ASE	Activated silica/ alumina column	(Pegoraro & Wannaz, 2019)
PCB	Air	$^{3}C_{12}$-PCB138 and $^{3}C_{12}$-PCB180	Soxhlet Extraction	alumina/silica column	(Chakraborty et al., 2013)
PCDD/DFs	Air	$^{3}C_{12}$-labelled PCDD/DFs	Soxhlet Extraction	multi-layer silica gel column and alumina	(Kim et al., 2008)
PeCB,	Air	PCB 121	automatic extractor	silica gel column;	(Roots et al., 2010)
OCPs	Air	TCmX and PCB-209	Soxhlet Extraction	Multilayer alumina/silica column	(Bajwa et al., 2016)
PBDEs, PCBs, HCH, DDT	Air	^{13}C PCB-105, d8 DDT and d10 Phenanthrene	Soxhlet extraction	Modified silica column	(Pozo et al., 2017)
HBCD	Sediment	$^{13}C_{12}$-labeled α-, β- and δ-HBCD	ASE	multi-layer silica column	(Oh et al., 2014)
PBDEs	Sediment	13C-DBDPE, 13C-BTBPE, 13CBDE209	PLE	gel permeation chromatography	(Lopez et al., 2011)
PBDEs and hexabromobi-phenyl	Sediment	BDE 28 and BDE 99	Solid-liquid chromatog-raphy	Modified multi-layer activated silica gel column	(Daso et al., 2016)
PeCB	Soil	PCB 121	automatic extractor	silica gel column	(Roots et al., 2010)
HCBD	Soil	TCmX	Ultrasonic extraction	Multi-layer silica-Florisil column	(Sun et al., 2018)
OCPs	Soil	Pentachloronitrobenzene and decachlorobiphenyl	Soxhlet Extraction	Florisil SPE cartridge	(Doong et al., 2002)

Table taken from Pavithra et al. (2023)

compounds, while Gas Chromatography is adopted for volatile compounds. A summary of analytical techniques for targeted POPs in water, air, soil, sediment, and biota matrices is provided in Table 6.3. Covaci et al., (2005) utilised GC-MS with an HT-8 capillary column for PBDE determination in electron capture negative ionisation (ECNI) mode, employing the selected ion monitoring (SIM) mode. Hao et al., (2019) analysed PCBs and PBDEs in air using a high-resolution gas chromatograph coupled with a high-resolution mass spectrometer (HRGC-HRMS). MS-TQ mass spectrometry for the analysis of various compounds, employing isotopic dilution met ionisation (ESI) in multiple reaction monitoring (MRM) mode. A GC-MS equipped with a CP-Sil 8 CB capillary column was used for PCB analysis in soil samples. LOD values varied between 0.0019-0.0023 ng/g dry weight (Chakraborty et al., 2016a). Table 6.3. lists the different instrumental methods used for the analysis of targeted POPs.

Table 6.3: Analytical methods of targeted POPs. Table taken from Pavithra et al., (2023).

Target compound	Matrix	Instrument techniques	Instrument column	LOD	Reference
PCBs	Air	GC-MS	CP-Sil 8	0.05 to 0.42 ng/sample	(Chakraborty et al., 2013)
PBDEs	Soil and sediment	GC-EI-MS	DB5HT	-	(Wang et al., 2011)
HBCD	Sediment	LC-MS/MS	XDB-C18	15 ng/L	(Oh et al., 2014)
PBDEs and BB-153	Water	GC-μECD	DB-5 MS	0.16 ng/L -BDE 153 and 1.54 ng/L - BB 153	(Daso et al., 2013)
PBDEs	Water	GC-EI-MS	DB5HT	0.85 to 1.98 ng/g for BDE-209	(Wang et al., 2011)
HBCD	Water	LC-MS/MS	XDB-C18	15 ng/l	(Oh et al., 2014)
PCBs	Water	GC-ECD	HP-5ms	0.25 to 1 ng/l	(Westbom et al., 2004)
PCBs	Water	GC-ECD	Rtx-5MS	ND	(Needham & Ghosh, 2019)
PeCB	Air	GC-MS/MS	-	0.52 pg/m^3	(Navarro et al., 2019)
HCBD	Air	GC-MS	DB-5MS	0.6 $\mu g/m^3$	(Liu et al., 2023)
Σ_{16}PFAS	Soil and Sediment	LC–MS/MS	C-18 column	0.001–0.156 ng/g	(Lee et al., 2020)

Target compound	Matrix	Instrument techniques	Instrument column	LOD	Reference
PCBs	Soil	GC-ECD	HP 5 Column	NA	(Sporring et al., 2005)
PCBs	Sediment	GC/ MS	CP-8 capillary column	NA	(Baqar et al., 2017)
HCBD	Soil	GC-MS	DB-5 MS	0.05 ng/g	(Sun et al., 2018)
Σ_9PFAS	Water	LC–MS/MS(- ESI mode)	C18 column	0.03 to 0.13 ng/L	(Gallen et al., 2014)
PCBs	Air	HRGC-HRMS	DB5MS	0.05 to 2.1 pg/ sample	(Hao et al., 2019)
PCDD/DFs	Air	HRGC/HRMS	DB-5(MS)	-	(Kim et al., 2008)
PCDD/DFs	Water	HRGC/HRMS	DB-5(MS)	0.01 to 0.05 pg/L	(Nie et al., 2013)
PeCB	Water	GC-MS/MS	HP-5MS	0.15 ng/L	(Wang et al., 2018)
HCBD	Water	GC-MS	DB-624	-	(Lei et al., 2021).
CLD	Water	UPLC/MS–MS	BEH-C18	6 to 11 μg/L	(Cimetiere et al., 2014)

Instrumental analysis for selected Stockholm Convention POPs

Chlorinated POPs

The presence and identification of hundreds of halogenated compounds in complex matrices makes separation of these compounds on the chromatographic column a challenge. Since the 1960s, chlorinated POPs have been determined using gas chromatography with electrochemical detector (GC-ECD), and in the last decades, the use of gas chromatography mass spectroscopy (GC-MS) has increased significantly. The mass spectrometry detector (MSD) is more specific than the ECD and will give more secure identification and often lower limits of quantification (LOQ). The GC system for the analysis of organochlorinated pesticides (OCPs) has been coupled to various MSD, including single quadrupole (Fang et al., 2020), triple quadrupole (Bolaños et al., 2007), ion trap (Fernandes et al., 2012), and time-of-flight (TOF) mass analysers (Cheng et al., 2016). All of them are capable of acquiring the accurate full mass spectra in both target and non-target modes. Different ionization sources, such as electron impact ionization (EI) and negative chemical ionization (NCI), have been applied in GC–MS for the determination of OCP residues.

Per and Polyfluoroalkyl Substances (PFAS)

Liquid chromatography (LC) coupled with ESI- or atmospheric pressure chemical ionization mass spectroscopy (APCI-MS) has been proposed as the standard method for analysis of PFOS and its salts. Many studies employed negative mode LC–MS/MS (Ullah et al., 2011). Other MSDs like TOF or ion-trap MS have also been used, e.g., to investigate PFAS in fish, sediment and water from a lake contaminated by PFAS from a paper factory (Langberg et al., 2020). A triple quadrupole MS is the most commonly used instrument for the quantification of PFOS (Hansen et al., 2001). Volatile PFAS, like fluorotelomer alcohol– FTOH have better sensitivity if they are analysed with GC-MSD (Jahnke et al., 2007).

Brominated flame retardants (BFRs)

Polybrominated diphenyl ethers (PBDE)

Gas chromatography coupled with EI-MS, especially HRMS, provides a reliable method for detecting PBDEs. Two ion masses are monitored at each level of bromination in the SIM (selected ion monitoring) mode. Both GC retention time and MS ion ratio may be used to identify individual congeners and reduce potential interference. GC-NCI-MS is also widely used in PBDEs analysis (Grung et al., 2021). GC-MS/MS is more and more used and probably has the best selectivity and sensitivity; GC-HRMS can also be used (Mackintosh et al., 2012). Liquid chromatography coupled with MS (LC–MS) has been adapted as an alternative method for PBDEs analysis. Electrospray ionisation (ESI) and atmospheric pressure chemical ionisation (APCI) showed a poor response to PBDEs, but atmospheric pressure photo ionisation (APPI) MS/MS gave better results for mono- to penta-BDEs in the positive ion mode and hexa- to deca-BDEs in the negative ion mode (Debrauwer et al., 2005). The most common chromatography column used for analysing PBDEs is 30 m × 0.25 mm × 0.25 μm. However, for detection of the highest molecular weight BDEs, like, e.g., BDE209, a significant degradation of these can be observed (Björklund et al., 2004). Thermal degradation can be minimised by using shorter and narrow GC columns with thin films, moderate injector and column temperatures, and short injector residence times by using pressure-pulse split-less injection (Wei and Li, 2010).

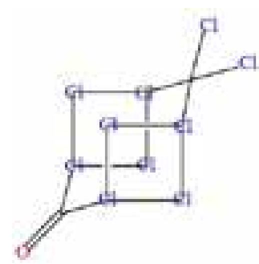
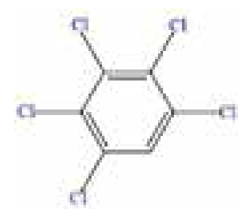
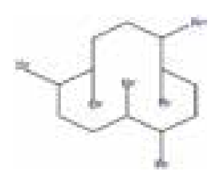
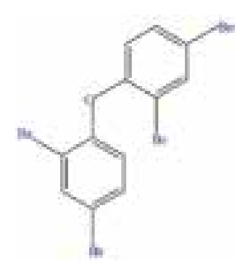
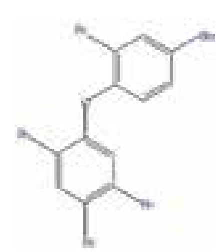
Hexabromocyclododecane (HBCDD)

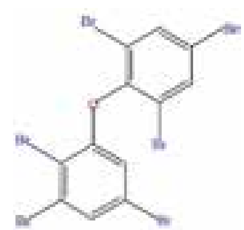
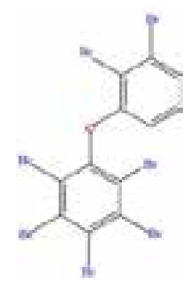
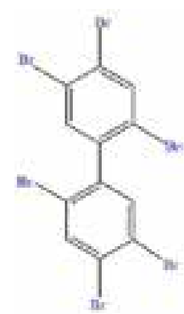
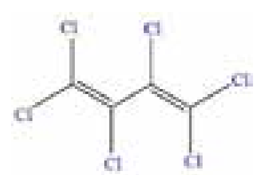
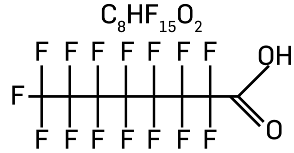
There are 16 potential stereoisomers, six diastereomeric pairs and enantiomers, as well as four mesoforms of HBCDD, but only three predominant diastereomers [($\pm$) α-, ($\pm$)β-, and ($\pm$)γ-HBCDDs] are commonly analysed (Marvin et al., 2011). Initially, total HBCDD was analysed by GC or GC-ECNI (electron capture negative ionization)-MS together with the PBDEs. However, isomer interconversion occurs in the inlet system at temperatures above 160°C, and decomposition starts above 220°C (Köppen et al., 2008). Therefore, reversed-phase LC–MS/MS is the preferred choice for these compounds and the only alternative for the analysis of the specific stereoisomers.

6.4 Overview of Targeted new POPs

Table 6.4 provides the physio-chemical characteristics of recently identified POPs such as chlordecone, hexabromobiphenyl, hexabromocyclododecane (HBCDD), pentachlorobenzene (PeCB), tetra-polybrominated diphenyl ethers (tetra-BDE), polybrominated diphenyl ethers (PBDEs), per and polyfluoroalkyl substances (PFASs), pentachlorobenzene (PeCB), hexachlorobutadiene (HCBD), hexachlorocyclohexanes (HCHs), and endosulfans. Additionally, it includes information on established or legacy POPs, encompassing polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/Fs), and DDT.

Table 6.4: Physiochemical Properties of Targeted POPs.

S. No.	Compound abbreviation	CAS No.	Mol. weight	Structural formula	References
1	Chlordecone	143-50-0	490.64	$C_{10}Cl_{10}O$ 	NCBI, (2022a)
2	Pentachlorobenzene	608-93-5	250.3	C_6HCl_5 	NCBI, (2022b)
3	Hexabromocyclododecane	3194-55-6	641.7	$C_{12}H_{18}Br_6$ 	NCBI, (2022c)
4	Tetrabromodiphenylether	5436-43-1	485.79	$C_{12}H_6Br_4O$ 	NCBI, (2022d)
5	Pentabromodiphenylether	60348-60-9	564.7	$C_{12}H_5Br_5O$ 	NCBI, (2022e)

S. No.	Compound abbreviation	CAS No.	Mol. weight	Structural formula	References
6	Hexabromodiphenyl ether	36483-60-0	643.6	$C_{12}H_4Br_6O$ 	NCBI, (2022f)
7	Heptabromodiphenyl ether	68928-80-3	722.5	$C_{12}H_3Br_7O$ 	NCBI, (2022g)
8	Hexabromobiphenyl	59080-40-9	627.6	$C_{12}H_4Br_6$ 	NCBI, (2022h)
9	Hexachlorobutadiene	87-68-3	260.8	C_4Cl_6 	NCBI, (2022I)
10	Perfluorooctanoic Acid [PFOA]	335-67-1	414.07	$C_8HF_{15}O_2$ 	(Pavithra et al., 2022)

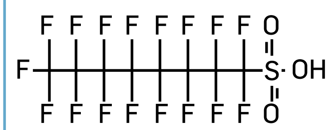
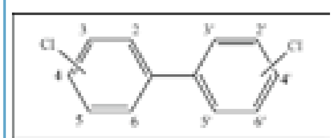
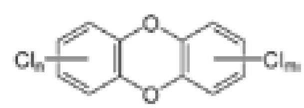
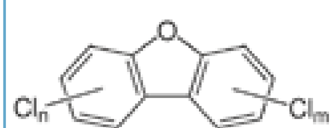
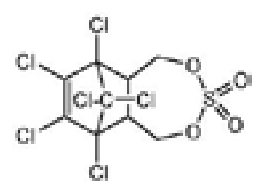
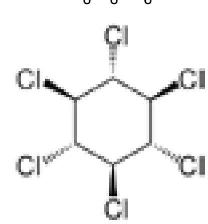
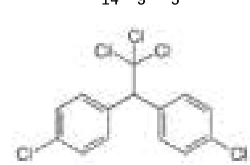
S. No.	Compound abbreviation	CAS No.	Mol. weight	Structural formula	References
11	Perfluorooctanesulfonic acid [PFOS]	1763-23-1	500.13	$C_8HF_{17}O_3S$ 	(Pavithra et al., 2022)
12	Polychlorinated Biphenyls[PCBs]	1336-36-3	326.4	$C_{12}H_{10-n}Cl_n$ 	(Pavithra et al., 2022)
13	PCDDs	40321-76-4	356.4	$C_{12}H_3Cl_5O_2$ 	(Pavithra et al., 2022)
14	PCDFs	57117-31-4	340.4	$C_{12}H_3Cl_5O$ 	(Pavithra et al., 2022)
15	Endosulfan	115-29-7	406.9	$C_9H_6Cl_6O_3S$ 	(Pavithra et al., 2022)
16	HCHs	608-73-1	290.8	$C_6H_6Cl_6$ 	(Pavithra et al., 2022)
17	DDTs	50-29-3	354.5	$C_{14}H_9Cl_5$ 	(Pavithra et al., 2022)

Table taken from Pavithra et al. (2023)

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Chapter 7
ENVIRONMENTAL AND HEALTH IMPACTS

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7.1. Review of Environmental Impacts of POPs

POPs in the environment can be classified into three categories: (1) Pesticides, which include hazardous OCPs like DDT, Heptachlor, and their by-products (α-HCH, DDD, DDE); (2) Industrial chemicals in the form of plasticizers, additives, or flame retardants (PCBs, PFAS, PCP, PBDEs); (3) By-products from industrial and decomposition process (PCDD/F, PCBs). Due to their diverse physicochemical properties, they are used for different purposes, making them important ingredients in various everyday products and industrial production processes.

Once used in industries, agriculture, or as by-products, these chemicals are released into the environment as gases or particles, or both, in the atmosphere and dissolved or particulate, or both, in water. This along with its persistence in the environment enables long-ranged transportation through the atmosphere and ocean (Jones, 2021). This means that any intentional, or accidental release from one country could expose a neighbouring or distant country to hazardous POPs, including the isolated parts of polar ice caps.

POPs are particularly concerning because of their potential toxicity and predominance in environmental media regardless of geographical proximity to civilization. They accumulate and persist in the

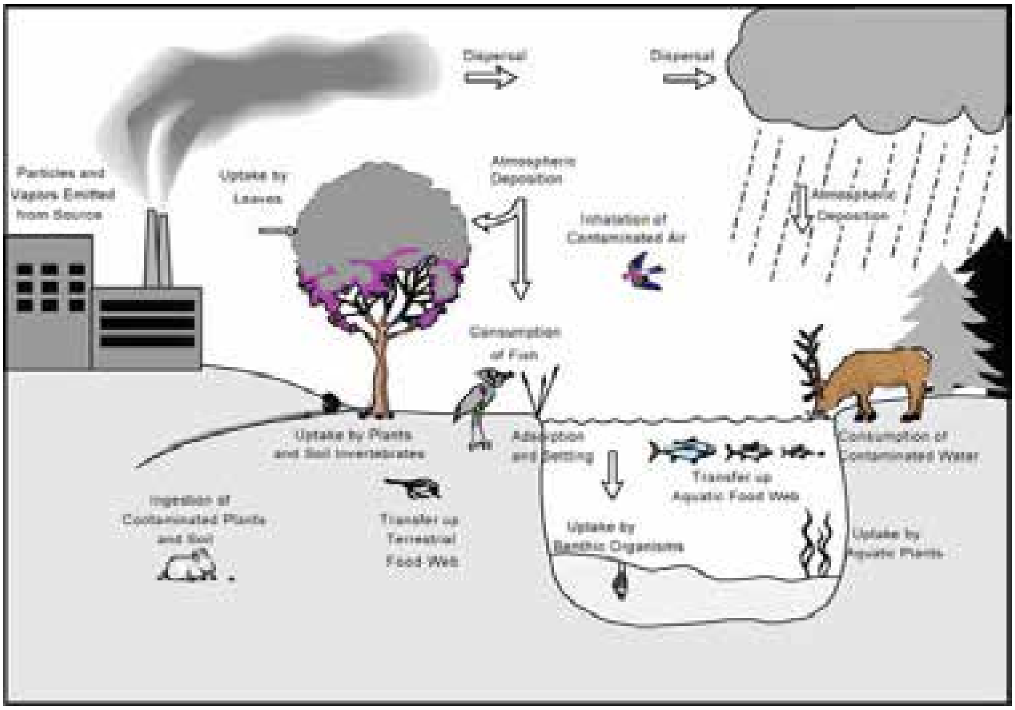

Figure 7.1: Persistent organic pollutants (POPs) from source to sink (Akhtar et al., 2021)

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fat deposits of exposed organisms, gradually spreading throughout the food chain and increasing in concentration from the producers to the top predators of remote regions, such as the pristine mountainous region (Kallenborn, 2006). Prolonged exposure to these chemicals can lead to sub-chronic and chronic effects, including impacts on the endocrine and reproductive systems (Grandjean et al., 2014), as well as on the immune response and behavioral and cognitive changes (Basterrechea et al., 2014). In humans, specifically, some compounds, even at low concentrations, can lead to health effects including cancer risk, increased risk of diseases such as endometriosis, diabetes, alteration of the immune system, neurobehavioral impairment, genotoxicity and increased birth defects (Ashraf, 2017; WHO, 2020). Therefore, to curtail the impact of POPs, assessment and monitoring of POPs in the environment is an essential precursor.

Water

POPs are ubiquitous in natural water systems. OCPs like Aldrin, Heptachlor, and , are most frequently measured at a concentration of 5.42-349.2 ng L^{-1} around Sembrong Lake Basin Malaysia (Sharip et al., 2017), higher than the International Standards established by WHO for drinking water. Perfluorooctane Sulfonate (PFOS) was detected off of the coastal wetlands in Valencia, Spain at a concentration of 47.8 ng L^{-1} (Lorenzo et al., 2019). A recent meta-analysis of existing studies of POPs in water indicates that the prevalence of POPs in surface water has increased over time and decreased in drinking and seawater (Vasseghian et al., 2021). This could be due to the result of excessive use in the agricultural sector leading to runoffs, incineration, and/or industrial waste. In the case of PCB pollution in coastal regions of Bangladesh, it's the import of PCB-containing capacitors, transformers, lubricating oils, ship breaking, etc. (Habibullah-Al-Mamun et al., 2019)

In India, legacy and emerging POPs have been detected across different ecosystems and their detrimental environmental impacts have also been well-documented for a considerable duration. Since the '90s several research studies have reported POPs, including DDT, aldrin, dieldrin, HCB, PCB, and chlordane in surface waters including major rivers and lakes (Sharma et al., 2014). In 2009, significant concentrations of OCPs were identified in the Gomti River, ranging from 2.16 to 576.49 ng/l. In the same year, high concentrations of DDT ranging from 1750 to 2430 ng/l were identified in the Cauvery River (Malik, Ojha, & Singh, 2009). Endosulfan sulfate, DDT, Endrin aldehyde, DDD, Endrin and Methoxychlor have also been detected regularly in Yamuna across all the seasons, indicating their wide use (Pandey et al., 2011). In 2012, a total of 28 PCBs were reported in a range between 14 - 1768 ng/L in surface waters of various sources, including Hindon and Yamuna rivers, canals, lakes, ponds, and drains from NCR Delhi (Kumar et al. 2012). In the same year, studies also observed DDT in the Ganges River, with concentrations spanning from 61 to 230 ng/l (Sharma et al., 2014).

More recently, studies have found PFAS compounds like PFOA and PFOS were detected along the East Coast. They were present in the highest concentration in the Ennore Coastal region (reaching a maximum of 24.8 ngL-1 and 13.9ngL^{-1}). Along the West Bengal coast, PFOA ranged from <1.5 to 14.0 ngL^{-1} and <1.3 to 8.2ngg^{-1} in water and sediment respectively. This contamination was heavily associated with industrial and domestic discharges (Hariharan et al., 2023).

Soil and Sediment

Soil and sediments play an important role in the mobilization of POPs across the environment (Wilcke, 2000). POPs can enter the soil through direct application or emission like in the case of OCPs in agricultural soil or indirectly through other contaminated matrices such as air or water. In aquatic systems, especially, sediments are important sinks and reservoirs for POPs discharged into the environment with the ability to remobilize these contaminants due to various digenetic processes (Pandey et al., 2011).

Globally, POPs like PCBs have been found at higher concentrations in the urban regions. In a study conducted in the Moscow region, the concentrations of the sum of 17 PCBs (PCB) in 35 bulk soil samples ranged from 3.1 to 42μg/kg. All concentrations and the degree of chlorination declined with increasing distance from Moscow (Wilcke et al., 2006) . Similarly, in a study of 5 Asian countries, the highest levels of polybrominated diphenyl ethers (PBDEs) were recorded at sites related to brominated flame retardants (BFRs) and e-waste recycling. At urban, rural, and background sites, PBDE concentrations followed this trend: urban > rural > background. Among the total PBDEs, BDE-209 was the predominant compound, while BDE-17, -85, -138, -191, -204, and -205 were the least abundant. The mean concentrations of total PBDEs (23 BDEs) in soils were highest in Japan, followed by China, South Korea, India, and Vietnam (Li et al., 2016).

Industrial pollution has also been highlighted in studies, such as one by Li et al. 2024, which found WHO-TEQ values for PCDD/Fs and dioxin-like PCBs in soil samples downwind of a contaminated industrial park, ranging from 6.52 to 16.7 pg g−1 dry weight. The sediment samples downstream showed concentrations between 2.25 and 34.6 pg g−1 (dw). The primary organochlorine pesticide (OCP) contaminants identified were hexachlorobenzene (HCB), p,p'-DDD, and δ-HCH, with concentrations of 3.7–1522.3 pg g−1, 38.2–2276.6 pg g−1, and < LOD–570 pg g−1, respectively. While long-distance atmospheric transport contributed to OCPs in soils, local sources were evident in areas heavily impacted by human activities.(Li et al., 2024)

The pervasive nature of POPs in soil can also be seen in ice-free soils in East Antarctica, where legacy POPs such as p,p'-DDD and δ-HCH were detected, and the concentrations of PCBs showed considerable variation, falling between 14.1 and 993.4 pg g−1. Higher concentrations of highly chlorinated PCBs were detected near contaminated sites and along major roads, suggesting a link to local activities. For PBDEs, levels ranged from 81.8 to 695.5 pg g−1, with BDE-209 being the most frequently found compound. The reduced levels of other BDEs in the soil could be due to the photodegradation of BDE-209 (Wang, et al., 2022).

In India, contamination can be primarily observed in agricultural areas that formerly used OCPs or urban localities with e-waste dumping sites and industrial areas. For example, PCDF congeners and maximum toxicity equivalents (TEQ) for both PCDDs (17 pg TEQ/g) and PCDFs (82 pg TEQ/g) had been reported at the dumpsite of Mandoli in New Delhi. This was related to intensive precious metal recovery process work going on in the dumpsite using the acid bath method (Chakraborty et al., 2018). PBDE (15 congeners) concentrations in grab sediments from Thane Creek were reported ranging from 15.98 to 132.72 ng/g dry weight in 2018 (Tiwari et al., 2018). Endrin, β-endosulfan, the isomers of HCH, 4, 4′-DDD, dieldrin and endrin aldehyde were reported to range from 6.35 to 118.29 ng/g in soil samples collected from Cardamom Hill Reserve Kerala in 2020 (Joseph et al., 2020).

Air

Air movement is considered to be one of the most significant and rapid routes for the global transport of most POPs. Multiple global air monitoring studies were carried out to support the Stockholm Convention on Persistent Organic Pollutants.
One such study was conducted in 2023 to assess OCPs, HCB, PCB and 242 for dioxin-like POPs concentration in the air across 43 countries in Asia, Africa, Latin America, and the Pacific. Total DDT and PCBs were the highest concentrations in about 50% of the samples. While some countries showed a decreasing trend for most OCPs, others showed high concentrations of legacy POPs. E.g. Total DDT in

the air from the Solomon Islands ranged from 200 to 600 ng/polyurethane foam disk (PUF) and countries like Barbados showed elevated levels of Dieldrin and Philippines Chlordane (De Boer et al., 2023) . Another study that analysed PFAS in 41 countries between 2017 and 2019 found high median values of PFOS and PFOA compared to PFHxS and other PFAS. GRULAC (Latin America and Caribbean Group) had the highest median value of PFOA (233 pg/PUF) and PFOS (192 pg/PUF) compared to Africa and Asia (Camoiras et al., 2021).

Recent studies have also suggested climate change as a contributing factor in the release of existing POPs in the air, especially in the arctic environment. Increasing temperatures, sea ice retreat, slumping permafrost, changing sea ice regimes, glacial loss and changes in precipitation patterns affect the distribution of contaminants in the arctic environment. Contaminants, including PCBs, BFRs and pesticides are well characterized in Svalbard glaciers in Norway. However, variable inputs PCBs across the years despite regulations indicate significant recycling within the environment(Hung et al., 2022). In a study conducted in Southwestern Svalbard, Hornsund, DDX composition indicated aged sources. The concentrations of DDXs and HCHs were a magnitude higher than the year-round monitoring done by stations in the High Arctic (Pawlak et al., 2024).

In India, aside from the rapid industrialization, there has been tremendous growth in e-waste collection sites which has increased the exposure of POPs like PCBs, Dioxins, and PBDEs in suburban sites. A 2021 study has analysed air samples from informal electronic waste recycling and allied sectors in Indian megacities. The study has reported dioxins in the range of 3.1 to 26 pg/m^3, and total PCBs were 0.5–52 ng/m^3 (Chakraborty et al., 2021). In India, POPs in the air can be predominately found in urban areas than rural areas and especially areas surrounding landfills and e-waste dumping sites. A study conducted in Chennai (one of the biggest e-waste dumping sites in the country), found a mean atmospheric concentration of 4616 ng/m^3, several orders of magnitude higher than suburban summer 1012 ng/m^3, and winter 43 ng/m^3. These suburban sites showed a significant increase from their last observation (Prithiviraj et al., 2020). Using a polyurethane foam-based passive air sampler, SCCPs and MCCPs in concentrations of 47.4 and 38.2 ng/m^3, respectively, were detected in the densely populated Colaba neighbourhood of Mumbai, in the western Indian state of Maharashtra (Chaemfa. et. al 2014).

Biota

Lipophilic POPs bind to organic matter present in both terrestrial and aquatic ecosystems, enter the body of organisms and get stockpiled in fatty tissue. This is a cause of concern because the higher the exposure of POPs through ingestion, the greater the risk for benthic species and sediment feeders and consequently for predators due to biomagnification (Mitra et al., 2019). Marine mammals are particularly susceptible to POPs accumulation in their blubber (Tanabe et al., 1981) and are at risk of associated effects such as developmental dysfunction, endocrine system disruption, reproductive failure and immunosuppression (Brouwer,et al., 1989). This has contributed to species and ecosystem decline like in the case of species in the Baltic ecosystem such as the grey seals *(Halichoerus grypus*), ringed seals (*Pusa hispida*) and white-tailed eagles (*Haliaeetus albicilla*) (Sonne et al., 2020).

Chemicals that are not bioaccumulative in aquatic food webs can biomagnify in terrestrial food webs. Even after decades of restriction, legacy POPs combined with emergent POPs have continued to be detected at high concentrations in apex predators posing significant risk (Cesh et al., 2010). A study conducted in Metro Vancouver, Canada detected PBDE at concentrations as high as 194µg/g lipid in Cooper's Hawk (terrestrial raptor) (Elliott,et al., 2015) and presented evidence of these POPs biomagnifying in the current terrestrial food web due to anthropogenic activities (Fremlin et al., 2020). In another study conducted near Holloman Air Force Base (New Mexico, United States) 20 of 23 species sampled were heavily contaminated with PFAS compounds. Perfluorooctanosulfonic acid (PFOS), was most abundant, with liver concentrations averaging >10,000 ng/g wet weight (ww) in birds and mammals, respectively. Aquatic bird and desert rodent communities each had liver PFOS $\bar{x}$>10,000 ng/g ww (Witt et al., 2024). This has also permeated into livestock and poultry food products where OCPs are predominant. In a study conducted in China, DDTs were found to be dominant in eggs, with the mean levels being 0.76 and 2.03 μg/kg for chicken eggs and duck eggs, respectively. Meanwhile, HCHs were highest in beef and lamb, with their mean levels being 0.51 and 0.65 μg/kg, respectively (Chen et al., 2024).

Similar assessments conducted in India revealed the occurrence of various POPs including DDT, heptachlor, aldrin, dieldrin, endrin, PCBs, HCB, and chlordane in the tissues of diverse aquatic species like fish, turtles, crabs, as well as terrestrial species such as lizards, earthworms, birds, lambs, goats, and even eggs (Agarwal et al., 2004). Notably, certain POPs, such as DDT, were detected in dolphins inhabiting the Ganges River, with concentrations reaching as high as 64,000 ng/g wet wt. In 2013, a study analysed organochlorine pesticides in buffalo milk samples collected from different localities of Delhi. In this study, DDT was detected in 70% of the samples while α and β endosulfan were detected in 35% and 40% of the samples analysed. The study also raises concern about the possible toxicological impacts of POPs on an infant's developing nervous and immune systems and reproductive organs (Aslam, et al., 2013). Similarly, DDT & HCH were reported in packaged milk samples collected from different cities of Uttar Pradesh & Madhya Pradesh (Negi, 2015).

This eventually makes humans more susceptible to toxicity from POPs exposure. A study conducted in Poland found that despite the decrease in the concentration of PCDD/F and PCBs in Baltic Fish, they are still unsafe for frequent consumption according to Tolerable Weekly Intake (TWI)[1] standards set by the European Food Safety Authority's (EFSA) (Mikolajczyk et al., 2021).

7.2 Human exposure routes/ pathways

Human exposure to POPs can happen in several ways, mainly through inhaling POP polluted air, consuming POP contaminated food through the intake of meat, dairy products, and particular foods derived from animals, and through dermal contact. The presence of POPs in food is associated to both, direct application of POP chemicals, e.g. pesticides, to protect or preserve the food, or indirect and unintentional transfer of POP chemicals present in food processing and packaging materials, which are known to further increasing POP exposure. The general human population is exposed to POPs through a variety of pathways. The most common exposure methods among these are direct inhalation, ingestion, and food (W. Guo et al., 2019).

Inhalation: According to (Huang et al., 2017), inhalation is a major exposure pathway for several POPs that can be found in the air as gases or volatile compounds. Inhalation exposure is an import exposure pathway for people working in close contact with the POPs. Employees in several industries may be exposed to POPs by inhalation, which is a serious cause of health concerns (Plunk & Richards, 2020). Professional workers who use pesticides, fungicides, paints, and other chemicals run a high risk of POP exposure (Yilmaz et al., 2020).

Ingestion: Ingestion is another important route of exposure to POPs. Soil ingestion can occur through hand-to-mouth contact with soil or dust. For example,

1 TWI is an estimate of the maximum amount of a contaminant that can be consumed in food or water that can be ingested weekly over a lifetime without risking adverse health impacts).

children who play in soil contaminated with POPs can ingest POPs in the soil by putting their hands in their mouths without washing (Van Wijnen et al., 1990). Indoor exposure is a potential pathway for exposure to PFAS via inhalation, ingestion of dust, and dermally (De Silva et al., 2021). Ingestion represents another significant pathway for exposure to persistent organic pollutants (POPs). Moreover, pesticides used in agriculture can contaminate fruits and vegetables, leading to the leaching of POPs into the food we consume (Tumu et al., 2023). In addition to soil ingestion and contaminated food, indoor exposure poses a potential pathway for exposure to perfluoroalkyl substances (PFAS). PFAS can enter our bodies through inhalation, ingestion of dust particles, and dermal contact, underscoring the need to address indoor sources of contamination to mitigate potential health risks (De Silva et al., 2021).

Diet:

Diet serves as a significant pathway for exposure to POPs for both humans and wildlife. These chemicals can be present in the food we consume, leading to potential health risks (J. Guo et al., 2022). High affinity of these chemicals for fats, leading to bioaccumulation in fat tissues of organisms and may cause biomagnification in the food chain. For instance, fish and shellfish can accumulate POPs in their tissues as they move through the food chain, ultimately reaching the human body when consumed. Additionally, dairy products, meat, and other animal-derived foods may contain POPs due to exposure to contaminated animal feed or water (Chakraborty et al., 2022). A study conducted in Norway revealed associations between the consumption of fish and seafood and serum concentrations of several perfluoroalkyl substances (PFAS) (Haug et al., 2010). It is noteworthy that over 90% of human exposure to POPs comes from the consumption of contaminated food, particularly food of animal origin. Fish stands out as one of the major sources of POPs exposure (J. Guo et al., 2022). Drinking water too is a potential exposure pathway for POPs with PFAS contamination becoming a major cause for concern (Wee & Aris, 2023).

Dermal Exposure:

Dermal exposure to POPs poses a significant health risk as these toxic chemicals can be absorbed through the skin. Individuals, especially workers in industries handling POPs, may experience direct contact, leading to absorption and systemic distribution. Pesticides, industrial solvents, and other POPs can cause adverse health effects, including skin irritation, dermatitis, and, in severe cases, systemic toxicity (Tang et al., 2021). The extent of dermal exposure depends on factors such as concentration, duration, and frequency of contact. Effective protective measures, such as personal protective equipment and workplace safety protocols, are crucial to mitigate dermal exposure and safeguard individuals from the harmful effects of POPs.

The assessment of exposure risks linked to POPs in contaminated sites and the surrounding environment is intricately connected to both the presence and activity of microorganisms within these ecosystems. Microbial dynamics serve as a critical indicator of the bioavailability of POPs, reflecting their potential uptake and movement through the ecosystem. However, the bioavailability of POPs is not solely determined by microbial activity; it is significantly influenced by the properties of the soil and sediment where these pollutants reside. Key factors such as the content and type of total organic carbon (TOC) play a crucial role in determining the extent to which POPs are accessible to microorganisms, even for bacteria. The TOC, along with factors like oxygen availability, affects how POPs are sequestered or released in sediments, influencing their mobility and degradation potential. Low oxygen levels can limit the breakdown of POPs, while well-oxygenated environments may enhance microbial degradation. This combination of environmental and microbial factors is essential for understanding the potential bioavailability of POPs, and consequently, their entry

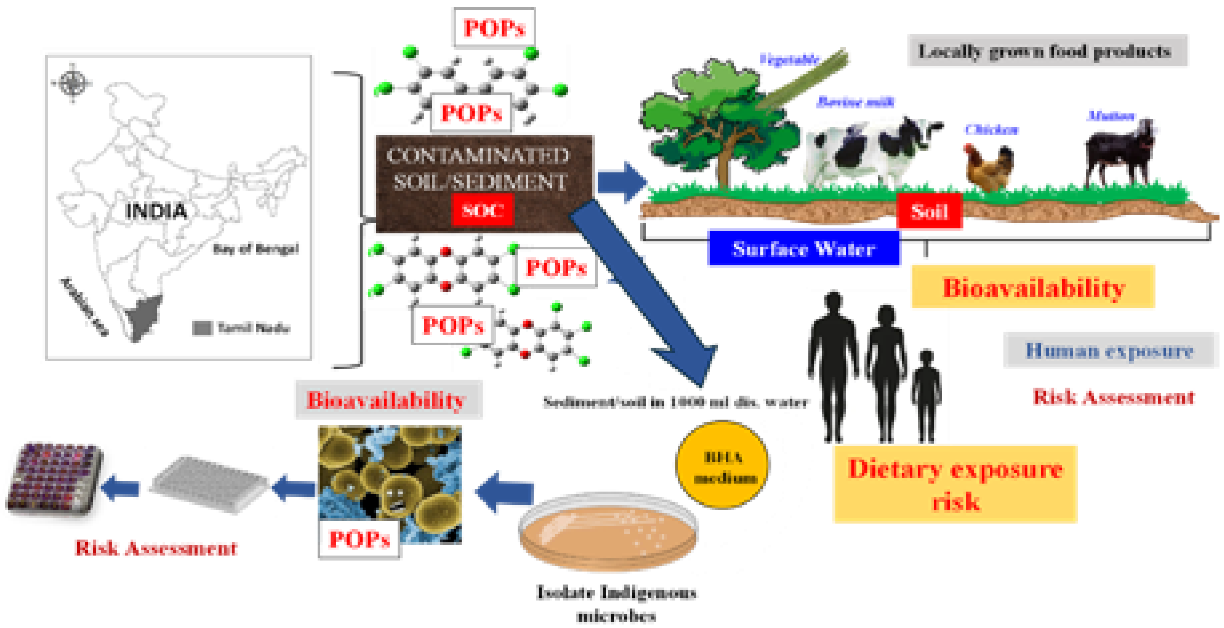

Figure 7.2: Exposure risk of POPs in the Environment

into the food web. Recognising the role of both biotic and abiotic factors offers valuable insights into the risks posed by POPs and aids in developing strategies for managing contaminated sites. (Jones & Voogt, 1999; Rajan et al., 2021).

7.3. Human Health Impacts

The detrimental effects of POPs were first unravelled in Rachel Carson's Silent Spring in 1962. The book talked about the damaging effects of DDT along with other synthetic pesticides on the ecosystem and hinted at their ability to cause low-grade hepatic cell carcinoma in humans (Carson, 1962). This sparked an increase in demand for better assessment of hazardous chemicals, especially ones that were similar to DDT like chlordane and heptachlor.
Many organochlorine pesticides (OCPs), like DDT, heptachlor, etc., are now recognised POPs and regulated under the Stockholm Convention. These classes of chemicals are hazardous and exhibit properties of persistence, biomagnification, and bioaccumulation. It poses a great risk to humans as they can assimilate in the fatty (adipose) tissues for a long time without degradation, gradually increase upon re-exposure and cause long-lasting damage (WHO, 2020).

Numerous epidemiological studies have linked POPs exposure to the development of metabolic (like diabetes), reproductive, neurological, cardiovascular, and developmental disorders (Fitzgerald & Wikoff, 2014). It can penetrate the placental barriers and put the growing fetus at high risk of cancer, benign tumors, neurological impairment, developmental issues, and even death. Small fat deposits, developing organs, and the inability to metabolize toxins make the developmental stages (fetus, infant, and child) critical windows of exposure (Damstra, 2002). Even if the children don't incur injury instantaneously, they have higher chances of developing it later in life, starting from contaminated breast milk during the early stages (UN, 2010). According to the World Health Organization, long-term exposure to dioxin is known to cause a certain wide range of toxicities, including reproductive, developmental, and neurodevelopmental effects (especially impaired semen quality), altered male-to-female birth ratios, immunotoxicity, and effects on thyroid hormones, liver and tooth development. Whereas short-term exposure to high

Table 7.1: Health problems linked to POPs (Rokni et al., 2023).

Health Impacts	POPs Type
Cancers	PCDE, PCN, PBE, PCBs, PAH, OCPs, PCBs, DDT, Endrin, PFOS and PFOA, Dioxins/Furans
Reproductive problems	HBCD, PBDE, PAHs, OCPs, Chlordecone, DDT, Hexachlorobenzene (HCB), PCBs
Endocrine disruption	HBCD, PCBs, Dioxins/furans, OCPs alpha, and beta hexachlorocyclohexane
Diabetes, Glucose intolerance, insulin resilience	PBDE, PCBs, OCPs, Dioxins/furans
Obesity	PBDEs, PCBs, OCPs
Cardiovascular problems	PBDE, PCBs, OCPs, Dioxins/furans
Kidney damage	Toxaphene, Mirex, Aldrin, α-, β-HCH, Dieldrin
Neurological disorders	PCBs, OCPs, DDT, Aldrin, Chlordane
Liver injury	PCBs, Aldrin, Chlordecone, Perfluorooctane sulfonate, HCB, PeCB, Toxaphene, α-, β-HCH, Chlordane
High blood pressure	Dioxins/furans, OCPs
Gastrointestinal distress	Aldrin, Chlordane
Respiratory diseases, Oxidative stress, DNA damage, Mutagenicity, and carcinogenicity	PAHs
Immune system, Immunological toxicity	Polychlorinated Dibenzo-p-dioxins (PCDDs), Pentachloorobenzene (PeCB)
Behavioral effects, Disturbances in mental development, Language delay, Cognitive dysfunction among children	PAHs, Dioxins/furans, HBCD

levels of dioxin may result in skin lesions, such as Chloracne patch and darkening of the skin, and altered liver function (WHO, 2019).

Over 90% of human exposure to POPs occurs via contaminated food, particularly in animal-based products (Rodríguez-Hernández et al., 2015). This contamination of food products occurs primarily via anthropogenic activities involving industrial and agricultural sectors. In a study conducted in Delhi, India, up to 55 legacy POPs, including their congeners, were detected in milk, yoghurt, and Indian cottage cheese. DDT congeners had the highest levels with the highest prevalence of DDE (up to 54.8ng/g l.w. in cottage cheese), while HCH, PCB, and PBDE were present in small concentrations across the different milk products. However, the highest concentrations of POPs were found in fish fillets (*p,p'*-DDE, 813 ng/g l.w. in fish) (Sharma et al., 2021).

Aside from the residual contamination from legacy POPs, the continuous occurrence of contamination of emerging POPs has become a cause of concern. Perfluoroalkyl substances, Brominated Flame

Retardants (BFR), and Short-chained Chlorinated Paraffins (SCCPs) have all been detected in breast milk, hair, blood, and urine in recent studies. A nationwide survey of Legacy and emerging per-and perfluoroalkyl substances (via hair), in India, found PFHXS, PFOS, and PFOA predominant in hair samples, and new variations like N-EtFOSA and 6:2 FTUCA were also detected (Ruan et al., 2019). Hair obtained from populations in the southern states of India contained more PFAS than in any other region of the country.

The impact of this accumulation and magnification is slowly being unraveled in India. A study conducted by the American Chemical Society, in 2019, on Asian Indian Immigrants in the United States found that the presence of DDT was directly linked to the risk of metabolic diseases among Asian Indians (Merrill et al., 2019). Recent studies in India have also linked the increase in the incidence of breast cancer in young women with OCPs like dieldrin, heptachlor, endosulfan, and HCH (Kaur et al., 2019). Exposure to food materials and occupational hazards were attributed as some of the main contributing factors in India. Liver and renal morbidities were also observed in workers of OCP-producing industries.

In countries like Singapore, high PFAS exposure has been linked with decreased fertility and fecundity in women (Cohen et al., 2023). South Korea, a country that has long banned PCBs, OCPs, and PFAS, has seen a slight increase in the environmental levels of these compounds. This has resulted in a considerable transfer of POPs to infants through human mother milk (Rokni et al., 2023). Even when the existing levels of the POPs decrease, their equally hazardous and persistent substitute replaces them. This was observed in Washington state in the US where even though PBDEs declined in breast milk overall, they were eventually replaced with other brominated flame retardants which increased in concentration (Schreder et al., 2023).

There is a decline in contamination levels of some legacy POPs compared to previous years (UNEP, 2024). This could be attributed to international interventions such as the Stockholm Convention and the rise in consumer awareness. However, fears surrounding the harmful impacts of emerging POPs, and alternatives of already restricted chemicals (e.g., BFR, PFAS, etc.) are still pertinent.

7.4 An overview of research studies on POPs in Tamil Nadu

Historically, research in Tamil Nadu has shed light on POPs exposure in human populations. In 1988, Tanabe et al. conducted the first study on POPs in Tamil Nadu, focusing on human breast milk samples collected from four representative locations: Madurai (urban), Chidambaram (suburban), Nattarasankotai (rural), and Parangipettai (fishing village). The study showed the HCH levels to be significantly higher than DDT and PCBs, especially among vegetarians (Tanabe et al., 1990). A follow-up study in 2009 revisited similar sites to quantify PCBs and PBDEs in human breast milk samples. This study, conducted in Chennai, Chidambaram, and Parangipettai, revealed a sharp decline in PCB levels compared to the 1988 study. In Chennai, PCB levels dropped from 110 ng/g lipid weight to 30 ng/g lipid weight; in Chidambaram, they decreased from 180 ng/g lipid weight to 8.2 ng/g lipid weight; and in Parangipettai, they fell from 72 ng/g lipid weight to 17 ng/g lipid weight. PBDE levels were significantly lower than PCBs in all locations, with higher levels observed in urban areas, except for suburban regions where PCB concentrations were relatively uniform.

In addition, Subramaniam & Solomon (2006) conducted a study in Madurai, targeting agriculturalists and non-agriculturalists to assess the variation in the body burden of organochlorine pesticides (OCPs), such as DDT and HCH. The findings showed notably higher levels of these pollutants in agriculturalists compared to other population groups, likely due to their occupational exposure. Research on POPs bioavailability in dumpsites in Chennai, involved studying indigenous microorganisms isolated from contaminated areas. The microbial consortia, including **Agromyces indicus** sp., **Pseudomonas resinovorans** sp., and **Pseudomonas stutzeri** sp., were used to assess the bioavailability of POPs like PCDD/Fs, PCBs, and PAHs. It was found that soil organic carbon (SOC) influenced the bioavailability of these compounds to the microbial consortia, although SOC did not show a significant correlation with the studied toxic contaminants. Low molecular weight PAHs and lighter PCB congeners exhibited higher bioavailability, particularly in pyrogenic and petrogenic sources within the dumpsite soils of Chennai (Rajan et al., 2021).

Human exposure assessments also extended to the dietary intake of locally sourced raw bovine milk samples from contaminated sites in Chennai and its suburbs. The geometric mean concentration of Σ25 PCBs in ng/g lipid weight followed a descending trend: electronic waste recycling (EWR) sites (13 ng/g lw) > open burning dumps (8 ng/g lw) > residential areas (4 ng/g lw). Over 80% of PCBs originated from EWR and open burning dumps before and after the COVID-19 pandemic (Rex & Chakraborty, 2024). In rivers like the Cooum and Adyar, concentrations of ΣHCH, ΣDDT, and ΣEndosulfan ranged from non-detectable to significant levels, with Σ25 PCBs also showing varied concentrations across the rivers (Rex & Chakraborty, 2022).

In another study, green mussels were used as bioindicators to monitor POPs in the environment. Research on green mussels collected from coastal areas in India (as well as Thailand and the Philippines) between 1994 and 1997 revealed that POP levels in mussels from Tamil Nadu and Pondicherry were significantly lower compared to streams and rivers in Northern India. However, high levels of DDT contamination were found in urbanized areas of Tamil Nadu, possibly due to the historical use of DDT for public health purposes (Tanabe et al., 2000). Collectively, these studies underscore the persistence and widespread impact of POPs in Tamil Nadu and beyond. Continued monitoring and intervention are essential to address the human health risks posed by POPs.

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Chapter 8
INTERNATIONAL BEST AVAILABLE TECHNIQUES (BAT) & BEST ENVIRONMENTAL PRACTICES (BEP) IN THE MANAGEMENT OF POPS

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8.1 Guidance on BAT and BEP – Stockholm Convention

8.1.1 Introduction

The Stockholm Convention defines **Best Environmental Practices (BEP)** as "the application of the most appropriate combination of environmental control measures and strategies.'' BEPs outline the utilization of the most suitable blend of strategies for chemical management and environmental control, encompassing optimal practices for enhancing the ongoing improvement of safety, health, and environmental outcomes.

Best Available Techniques (BAT) are defined as ''the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for release limitations designed to prevent and, where that is not practicable, generally to reduce releases of chemicals listed in Part I of Annex C (of Stockholm Convention (SC) and their impact on the environment as a whole''.

Article 5 of the SC requires Parties to develop action plans to address the release of hazardous chemicals, including the use of BEP and BAT. For new sources of pollutants, Parties are obligated to promote and potentially mandate the use of BAT within specific source categories and encourage the adoption of BEP for these categories. Additionally, for those categories of new sources that have not been addressed above, the Parties are encouraged to actively promote the adoption of BAT and BEP. This approach ensures that various potential sources of pollution are adequately managed and regulated to minimize their impact on the environment and human well-being.

The initial focus should be on source categories identified in Part II of Annex C, and the requirement for adopting BAT for these categories should be phased in as promptly as feasible. For existing sources, Parties are encouraged to promote the use of BAT and BEP for Part II and Part III source categories listed in Annex C. The Convention emphasizes the importance of adopting standardized guidelines for these practices to foster effective pollution management and international collaboration in the fight against POPs.

The Conference of the Parties (COP) to the Stockholm Convention, at its first meeting held in May 2005, decided to establish an Expert Group on BAT and BEP with a mandate to complete further work on the enhancement and strengthening where need be (decision SC-1/19). The Group contains experts nominated by Parties to the Convention and others including industry bodies and civil society organisations that are observers at the Convention

The review and update of the guidelines and guidance on BAT and BEP, conducted by the Expert Group, is an ongoing and continuous process in accordance with decision SC-8/6 of the SC. Currently, BAT and BEP guidance documents are available for:

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- BAT and BEP relevant to Article 5 and Annex C of the SC
- Use of PFOS, PFOA, and their related compounds listed under the SC
- Polybrominated diphenyl ethers (PBDEs) listed under the SC
- Use of hexabromocyclododecane (HBCD) listed with specific exemptions under the SC
- Production and use of pentachlorophenol listed with specific exemptions under the SC
- Identification and management of sites contaminated with POPs

8.1.2 Guidance on BAT and BEP relevant to Article 5 and Annex C of the SC (SC on POPs, 2021a)

The document provides a brief description of the characteristics and risks of chemicals listed in Annex C of the SC, directly relevant provisions of the SC and a summary of measures mandated under these provisions. It also provides guidance on the consideration of alternatives, including a checklist that may be used in applying BAT to new sources. In addition, it includes general guidance, applicable principles and descriptions of considerations that cut across multiple source categories.

8.1.3 Guidance on the use of PFOS, PFOA, and their related compounds listed under the SC (SC on POPs, 2021b)

The Expert Group has recommended general BAT and BEP measures such as proper storage, preventing worker exposure, minimisation/optimisation of chemicals used, and preventing release to the environment by using dust collectors or scrubbers. The document details BAT to phase out the remaining acceptable uses of PFOS and its salts (insect baits with sulfluramide for control of leaf-cutting ants, metal plating (functional chromium plating) in closed-loop systems and fire-fighting foam). For example, BAT identifies the use of fipronil and deltamethrin, and the Thermal Fogging Technique as alternatives to PFOS in its insecticidal use, and lists both fluorinated and fluorine-free alternatives to PFOS-based fire-fighting tools.

The document also identifies BEP to limit contamination for each acceptable use. For its insecticidal use, the guidelines suggest -

- Requiring qualifications and periodic training for operators
- Calculating precise dosage to prevent under- or over-dosing
- Applying only to dry soil and in dry weather, unless bait stations are properly used
- Assessing bait consumption and control efficiency
- Collecting and properly disposing of left-over pellets (e.g. waste incineration)

For its use in fire-fighting foams, the guidelines suggest the use of fluorine-free foams for training, providing for containment, treatment, and proper disposal of any foam solution, development of firewater runoff plans, containing and collecting firewater runoff, and treating firewater runoff with a combination of suggested methods before safe disposal.

8.1.4 Guidance on BAT and BEP relevant to the polybrominated diphenyl ethers (PBDEs) listed under the Stockholm Convention

In May 2017, the SC CoP listed decabromodiphenyl ether (decaBDE), also known as BDE-209, in Annex A of the Convention. The listing includes specific exemptions for the production and use of commercial decaBDE in vehicle and aircraft parts, textiles, home appliances and housing insulation, where the fire-retardant property of the compound is utilised. The guidance document suggests several BAT and BEP methods for using decaBDE. This includes:

- Improving raw material handling to prevent exposure and leaks
- Improving the compounding process to reduce dust formation and volatilisation

- Improving conversion/back-coating process in polymers and textiles to minimise atmospheric emissions
- Designing textiles to be wash-resistant without losing their flame-retardant property to prevent emissions from washing
- Replacing decaBDE with another flame retardant
- Replacing base polymer containing decaBDE with a less flammable material, to reduce the need for flame retardants
- Redesigning electrical and electronic products to prevent ignition and reduce the need for flame retardants

The Expert Group has outlined BAT and BEP for environmentally sound recycling of PBDE-containing articles, from the separation of plastics to incineration and energy recovery. Essential features for an Environmental Management System (EMS) to qualify as BEP are listed in the guidance document. These include commitment, leadership and accountability of management for the implementation of an effective EMS; the identification of the needs and expectations of interested Parties; establishing objectives and performance indicators about significant environmental aspects; planning and establishing necessary procedures to achieve the environmental objectives of the organisation; and establishing performance checks and taking corrective action.

The guidance document also outlines a material/waste management system to ensure the traceability of PBDE-containing materials and waste. It suggests a pre-acceptance procedure to improve the knowledge of incoming materials and wastes; techniques for storage and handling to prevent environmental contamination and improve worker safety; and improving the knowledge and management of outgoing wastes or material.
The Expert Group has suggested that Producer Responsibility can be the key to the global management of PBDEs, pointing to cases from the EU and OECD where producers' and other stakeholders' responsibility has been established. It also discussed the monitoring of PBDEs in polymers and the introduction of a Life Cycle Management system.

BAT and BEP measures specific to the accepted uses of decaBDE have been listed, including measures for the reduction of channeled emissions, monitoring of diffuse Volatile Organic Compounds (VOC) emissions, measures to prevent or reduce diffuse VOC emissions, measures relating to wastewater emissions, labelling of PDBE-containing articles, and the availability of alternatives.
It also listed measures to prevent releases of decaBDE during different processes like handling, compounding process, conversion process, transport and storage, and disposal of packaging at the end of the production process.

The Expert Group suggested measures to phase out the use of decaBDE as a flame retardant in plastics, textiles and building insulation; the POP can be replaced with other flame retardants; both halogenated and non-halogenated alternative flame retardants are listed. Apart from this, the use of fire-resistant plastic/fabric, fire barriers and intumescent systems (a substance that swells as a result of heat exposure), or a change in design can help eliminate or reduce the need for chemical flame retardants.
The guidance document discusses BAT and BEP for environmentally sound recycling of PBDE-containing articles, including PBDE-containing plastics used in Electrical and Electronic Equipment (EEE), vehicles and polyurethane foam and lists technologies to separate PBDE-containing materials for recycling.

8.1.5 Guidance on BAT and BEP for the use of hexabromocyclododecane (HBCD) listed with specific exemptions under the Stockholm Convention (SC on POPs, 2021c)

HBCD is an additive-type flame retardant that is not chemically bound to the matrix. The chemical was listed in Annex A of the Stockholm Convention in 2013, with specific exemptions for production as per provisions of the Annex, and for use in expanded polystyrene (EPS) and extruded polystyrene (XPS) in buildings. The guidance document on HBCD contains both general and specific BAT and BEP measures for the use of HBCD.

The general guidelines include:

- regular inspection and maintenance of plant and equipment;
- monitoring of emissions/releases;
- substitution of harmful/hazardous substances;
- limiting the number of emission points;
- implement and adhere to a well-designed EMS;
- specific education and training of employees;
- consider environmental impact right from the design stage, covering the complete life cycle;
- measures related to chemical knowledge, storage, handling, dosing, dispensing and transport;
- minimization/optimization of the chemicals used;
- measures related to engineering, design and equipment; and
- procedures for spills/leaks as well as waste management.

In addition, the Expert Group has suggested specific BEP applicable to the use of HBCD in EPS/XPS in buildings. This includes measures for the reduction of channeled emissions, measures to monitor, prevent or reduce diffuse emissions, measures relating to water emissions, minimisation and control of emissions from storage, recovery of all purge streams and reactor vents, collection and treatment of exhaust air from pelletising, and emission reduction from the dissolving system in high-impact polystyrene (HIPS) processes. The guidance document also lists the BAT to reduce channeled emissions of organic compounds to the air, viz., adsorption, absorption, catalytic oxidation, condensation, and thermal oxidation.

In addition, alternatives to the use of HBCD in EXP/XPS in buildings have been discussed. Substitution of HBCD can take place at two levels – a) replacing the POP with a less hazardous chemical alternative; b) replacing the insulating material/resin with stone wool, glass wool, phenolic foams etc. so that the addition of fire-retardant polymer is no longer required. The document lists considerations for identifying, screening and labelling of HBCD-containing products and articles, and considerations for environmentally sound management of contaminated sites.

8.1.6 Guidance on BAT and BEP for the production and use of pentachlorophenol (PCP) listed with specific exemptions under the Stockholm Convention (SC on POPs, 2021d).

PCP and its salts and esters were listed in Annex A of the Stockholm Convention in May 2015, with specific exemptions for use in utility poles and cross-arms by the provisions of the Annex. Apart from general BAT and BEP for the management of chemicals, the guidance document lists measures specific to the production and the use of PCP. Gravity separation is the primary treatment method suggested to recover oil and the associated chlorophenol for recycling and treatment. Microorganisms during secondary treatment degrade roughly 90% of most chlorophenol waste, provided that they are acclimated to the waste, and precautions are taken against shock loadings. As a pre-treatment operation, adsorption on activated carbon can be performed to remove chlorophenols from the waste streams. The final disposal of the concentrate and the adsorbent should take place in accordance with the Basel Convention.

During the use of PCP in wood preservation, the application of the preservative can take place through one of two processes – pressure treatment or thermal treatment. In both processes, there is a potential for chemical release through drips, spills, vapours, precipitation etc. or in the form of sludge or effluent. Preventing accidental release of PCP into the environment requires that BAT and BEP measures are taken during the entire procedure, including site operation (receiving, storing and handling of pesticides), wood conditioning and treatment, and storage after treatment. The document suggests techniques for managing the controlled release of effluents into the environment (air, water and soil).

The Expert Group has listed several chemical alternatives to PCP, viz., chromated copper arsenate (CCA), creosote-based products, ammoniacal copper zinc arsenate (ACZA), ammonium copper quaternary (ACQ), copper naphthenate, copper azoles and azoles/permethrin combinations, polymeric betaine, copper and/or boron-based products, and 4,5-dichloro-2-n-octyl-4-isothiazolin-3-one (DCOIT). However, they note that some of these alternatives contain toxic, or even carcinogenic substances, resulting in their use being restricted.

The guidance document also identifies a number of functional, non-chemical alternatives to PCP-treated wood poles such as concrete, steel, fibre glass reinforced composite (FRC) or the undergrounding of utility wires. Initial costs to manufacture and install such functional alternatives to PCP-treated wood poles and/or cross-arms may be significantly higher than for PCP-treated wood poles. However, the lifecycle costs of the functional alternatives, along with their health and environmental profile, can be either better or worse than treated wood. The document concludes by listing the types of sites with potential for PCP contamination and the considerations that need to be made for the environmentally sound management of these sites.

8.2 BAT and BEP guidance for the management and recycling of POPs and their waste

In the context of waste management and recycling of POPs, BAT and BEP are important concepts that play a crucial role in minimizing the release and exposure to these hazardous substances.

BAT is a dynamic concept and refers to the most effective and advanced methods and technologies available to prevent or minimize the release of POPs into the environment. For example, the textile industry covers a variety of activities, such as yarn and fabric production, wet processing like bleaching and dyeing, finishing, and coating. Various environmental issues stem from the textiles industry such as the use of hazardous chemicals, polluted effluent, emission of microplastics as well as water, energy, and material consumptions. Additional environmental considerations include land use and degradation for the production of agricultural raw materials, their consumption, and energy used during processing. Such issues can be addressed through BAT regulations relevant for the textile manufacturing industry. The Best Available Techniques Reference Document (BREF) for the textiles industry published in 2023 specifies the use of fibres and filaments with minimal contamination from pesticides, manufacturing residues, mineral oils, and sizing chemicals. To verify minimal contamination, BAT also monitors the incoming contaminants through in-house testing, coordination with suppliers, or certification schemes and standards.

According to BAT 9 regulation for water use and wastewater generation, production optimization can be implemented through the scheduling of combined processes, which reduces the overall water consumption and wastewater generation. Furthermore, water reuse and recycling techniques are also outlined that maximise resource efficiency. (OECD, 2022).

The BREF for the Food, Drink, and Milk Industries addresses the treatment and processing of animal and/or vegetable raw materials, whether processed or unprocessed, with the purpose of producing food or feed, as well as packaging. This document addresses the safety of food and feed in terms of impurities, pesticide residues, water quality fit for human consumption, government control of food products, and materials that come into contact with food (European Commission, 2024).

Also, in 2021, the SC Guidelines on BAT (and BEP) provide the necessary guidance to minimize their releases of POPs from unintentional production as per Article 5 of the Convention, including (SC on POPs, 2021a):

- Use of PFOS, PFOA, and their related compounds listed
- Relevant to the listed PBDEs
- Use of HBCD listed with specific exemptions
- Production and use of pentachlorophenol listed with specific exemptions
- Draft guidance on the identification and management of sites contaminated with POPs

BEP (Best Environmental Practices):

BEP concept involves the implementation of specific management practices that can effectively control the release and exposure to POPs. These practices should consider factors such as environmental impact, risk assessment, and socio-economic factors. BEPs are aimed at minimizing the impact of POPs on human health and the environment.

Waste Management and Recycling of POPs:

Waste management and recycling play a crucial role in reducing the environmental burden of POPs. Here are some key aspects of managing POPs waste:

BAT can serve as a policy tool for setting the emission limit values that can prevent and control industrial emissions, thus ensuring a high level of human health and environmental protection.

The waste collectors and local communities who are the vulnerable ones should be trained on chemicals and waste management, and proposed together the way forward to apply with BAT/BEP measures needed to reduce or eliminate the releases of POPs and technical guidelines of environmentally sound management of wastes including chemicals. The collaboration and ownership of various stakeholders such as the local authorities, communities, Civil Based Organizations, private sector, and academic institutions are important for efficient POPs management specifically, and waste management in general, for achieving sustainable development. Significant environmental degradation and pollution can have a major negative impact on public health, in the absence of environmentally sound waste management systems (Bavuge et al., 2020). BAT are those which may be established at the level of each industrial sector or activity in order to prevent or reduce emissions and the impact on the environment as a whole. Regulatory authorities typically set requirements for installation operations to prevent or reduce emissions to air, water, soil, energy and water consumption, and waste management through treatment or disposal. This is presented in Figure 8.1.

The procedures for establishing BAT aim to consider the most effective technologies and methods available considering the cost and the required site-specific environmental protection benefits. But at the same time, broad accounting of upstream and downstream interactions proves to be difficult in such contexts. When determining BAT for sector-specific activities, consideration of up- or downstream interactions of the sector's value chain may possibly have limitation. A sector specific activity may be impacted by upstream suppliers and affect downstream activities including further processing or consumer use that are not necessarily considered in BAT determinations. Additionally, the sector of focus could impose requirements upon upstream markets or be affected by downstream regulatory or market requirements. Generally, the establishment of BAT regulations focuses mainly on dealing with industrial activities individually, in isolation. In such cases, there is the possibility that the identified BAT approaches do not adequately consider interactions with other industries and actors.

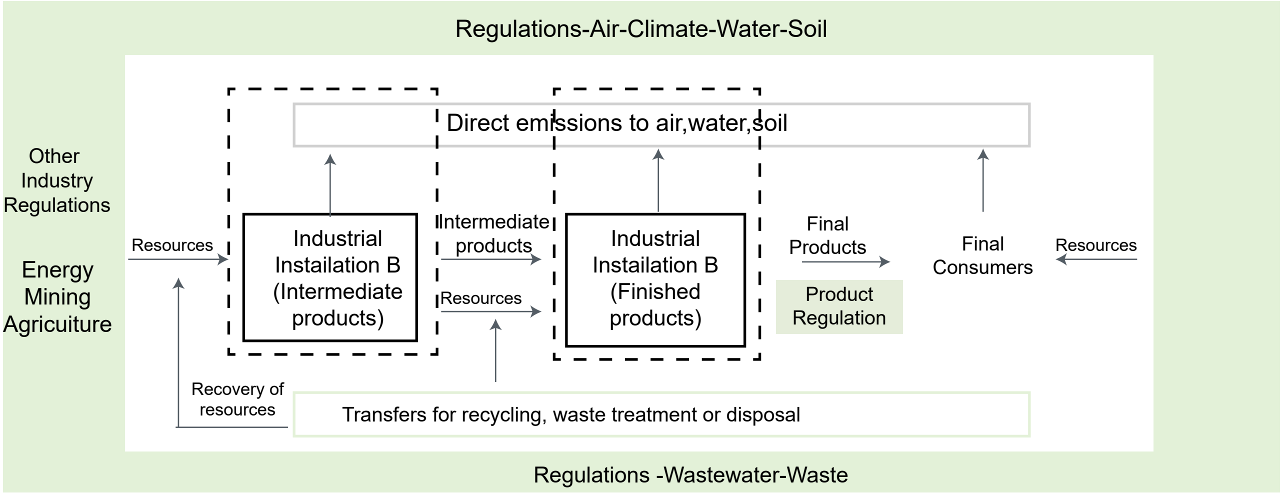

Figure 8.1: Illustration of BAT regulatory framework
Notes:
1. Dashed lines represent the industrial installation/activity regulated by BAT. Certain activities may supply materials to other regulated industries.
2. Grey dotted sections represent market interactions that may influence use of resources and products at each stage.
3. Framing the illustration are multiple regulations that protect natural resources, environment, and human health.

Value chain approaches for determining BAT

Any of the following four concepts can be applied as a lens by which we can assess the sector interactions during a country's BAT determination process (OECD, 2022):

1. **Green Chemistry:** It involves the identification of alternative chemicals and technologies that are economically competitive and can offer advantages for industry and consumers, and those which are environmentally advantageous.

2. **Resource efficiency:** Maximising resource efficiency that can achieve cost savings as well as reduction in the emissions.

3. **Circular Economy:** Identification of alternative materials and technologies that enables waste reduction and promotes recycle and the use of secondary and reusable materials and energy efficiency throughout the whole value chain.

4. **Decarbonisation:** Consideration of BAT through decarbonisation and greenhouse gas (GHG) reduction lens may result in the identification of further potential for the reduction of GHG emissions, at the industrial installation, as well as throughout the value chain (IOMC, 2024).

Identification and Segregation: Identification of materials containing POPs is critical for proper waste management. Segregation of waste containing POPs from other waste streams is essential to prevent contamination and ensure safe handling.

Storage: POPs waste should be stored securely in appropriate containers and facilities to avoid leaks or spills that could lead to environmental contamination.

Recycling and Recovery: In some cases, recycling and recovery of POPs from waste may be possible. However, this process must be carried out carefully to prevent re-introduction of POPs into the environment.

Disposal: If recycling or recovery is not feasible, safe disposal methods that comply with BAT and BEP should be used. This may involve secure landfilling or deep burial in designated facilities.

International Collaboration: Given the global nature of POPs pollution, international collaboration and agreements (such as the Stockholm Convention on POPs, Basel Convention, Rotterdam Convention, Convention on Long-Range Transboundary Air Pollution, and Minamata Convention) are crucial in tackling the issue. This includes sharing information, best practices, and providing support to developing countries for sound waste management. It's important to note that handling POPs waste requires specialized knowledge and expertise due to the hazardous nature of these substances. Therefore, waste management of POPs should always be conducted by trained professionals and in compliance with relevant regulations and guidelines. However, it's essential to understand that data gaps in the field of POPs waste management and recycling may exist due to various reasons. Some potential factors contributing to data gaps include:

Limited Monitoring: The monitoring and tracking of POPs waste generation, management, and recycling practices are limited in some regions or countries. This is due to inadequate resources, infrastructure, or lack of regulatory enforcement.

Incomplete Reporting: Not all countries or industries consistently report their POPs waste management and recycling data. This results in incomplete datasets, making it challenging to assess the overall global situation accurately.

Data Collection Challenges: Collecting accurate data on POPs waste management and recycling can be complex due to the diverse range of substances involved, their sources, and the various methods used for their treatment and disposal.

Lack of Research: The field of POPs waste management and recycling is continuously evolving, and research efforts may not cover all aspects comprehensively. Some specific POPs or waste types have less available data compared to others.

Confidentiality and Trade Secrets: Companies or industries dealing with POPs waste management and recycling generally withhold some information due to confidentiality concerns or to protect trade secrets.

Addressing data gaps is crucial for effective policymaking, risk assessment, and decision-making in POPs waste management and recycling. Governments, international organizations, and researchers must collaborate to improve data collection, enhance monitoring systems, and encourage transparent reporting to bridge these gaps. Data sharing, standardized reporting formats, and increased research funding can all contribute to closing the data gaps in this critical area.

As stated earlier, in September 2021, BAT and BEP were the critical concepts introduced under the Stockholm Convention on POPs but are widely applicable for waste management practices related to different waste categories including POPs (SC on POPs, 2021a).

Work planned over 2021-2022 in India

- Continue to collect, compile, and evaluate new technical information on BAT and BEP pertaining to the chemicals listed in Annex A, B and C of the Convention and evaluate the need to prepare or update guidance documents.
- Continue to work on updating or developing guidance for the POPs listed in Annex A, B and C with acceptable purposes or specific exemptions subject to the need for guidance on BAT and BEP. The priority areas of work include:

i. Collect and evaluate relevant technical information and initiate the development of guidance on BAT and BEP relevant to short chain chlorinated paraffins (SCCPs);

ii. Collect and evaluate further information pertaining to the review and update of the guidance on BAT and BEP for the use of PFOS, its salts and PFOSF, and PFOA, its salts and PFOA-related compounds and related chemicals listed under the Stockholm

Convention to include additional aspects relevant to BAT and BEP for PFOA, especially on uses and relevant BAT/BEP measures;

iii. Initiate work to address further newly listed POPs in view of possibly amending the guidance on BAT and BEP for the use of PFOS, its salts and PFOSF, and PFOA, its salts and PFOA-related compounds and related chemicals listed under the Stockholm Convention to incorporate aspects relevant to PFHxS that are listed.

iv. Collect information from Parties and others on the successful application of BAT and BEP to minimize and ultimately eliminate releases of the chemicals listed in Annex A, Band C to the Convention, in particular PFOS, and share broadly such examples of best practices.

The guidance documents relevant to chemicals listed in Annex A, Band C of the Stockholm Convention represent a useful source of information to assist Parties in acquiring knowledge on and implement their actions for minimizing and/or eliminating releases of these chemicals.

8.3 Review of International Management Experiences and Best Practices

Since its adoption in 2001, the Stockholm Convention has listed 31 POPs, including several new chemicals that are listed as candidate POPs. The countries worldwide find themselves grappling with the multifaceted challenges presented by these emerging POPs, therefore enhancing the importance of embracing international management experiences and best practices. The countries have adopted different approaches and by examining international experiences and best practices in managing POPs, policymakers and stakeholders can develop more effective strategies to tackle the issue of POPs contamination. The management of POPs requires a multifarious approach that encompasses scientific knowledge, regulatory frameworks, and cooperation among nations. The present chapter largely focuses on the global best management system in place by the countries to manage the POPs, as the global regulatory practices to manage the POPs are already discussed in Section 4.2.

There is a role of international agencies such as the United Nations Development Programme (UNDP) and the World Bank in assisting the Global Environment Facility (GEF)-funded projects to 84 developing countries and countries with economies in transition since 2004. Their efforts are focused on the sustainable management of the use, disposal, and destruction of POPs. In collaboration with private sector partners and NGOs, they have introduced life cycle management of POPs and affordable alternative approaches and technologies. As a result, they have safely disposed of 18,203 tonnes of POPs, thereby reducing the risk of direct exposure to these harmful substances for 2.5 million people (UNDP, 2019).

Some of the international management experiences and best practices in different countries are highlighted below:

Egypt (World Bank, 2022)

Sustainable POPs Management Project in Egypt

Between 2014 and 2021, with support from GEF through the World Bank, the 'Sustainable POPs Management Project" successfully disposed of 1500 tons of hazardous chemical stockpiles in 80 locations spread across Egypt, comprising obsolete pesticides and PCBs. The project followed a "learning by doing approach" to achieve its overall objective of improving the management and disposal of targeted stockpiles of obsolete pesticides including POPs and PCBs (World Bank, 2023).

- This approach helped to achieve its objective of safe disposal of POPs and facilitated the capacity-building of officials from the Ministry of Environment (MOE), Ministry of Agriculture and Land Reclamation (MALR), and Ministry of Electricity and Renewable (MERE) for the safe disposal of POPs.

- By working closely with international consultants and contractors, these ministries built their capacity for identifying, assessing, repackaging, storing, transporting, and disposing of POPs following international best practices.
- The project adopted an innovative "co-processing technology" in which the obsolete pesticides were used as fuel to fire the boilers and operate kilns in local cement industries, that not only saved the cost of sending obsolete pesticides abroad for incineration but established a model for future disposal of obsolete pesticides in Egypt.
- The project also used an innovative approach to decontaminate PCB oils in electric transformers, by treating them, while they were in use (through an online treatment method without decommissioning) and use of technologies without sodium and lithium salts to avoid fire hazards. This enabled quick and safe treatment of PCBs in an environmentally sound manner and marked the first time that this technology had been used in the Middle East and North Africa (MENA) and one of the few cases globally.
- This project procured PCB decontamination equipment, thereby enabling the engineers of MERE to conduct the entire PCB oil treatment and decontamination process. This measure saved the cost of hiring an international contractor for treatment and built in-house infrastructure and capacity at the MERE.

Turkey

POPs Legacy Elimination and POPs Release Reduction

The Ministry of Environment and Urbanization in Turkey has successfully implemented the GEF-funded project in collaboration with UNDP and United Nations Development Organization (UNIDO) from 2016 to 2020. The progress made under this project (UNDP, 2021) (UNDCS Turkey, 2016-2020)

About 2,500 tons of stockpiled high-concentration POPs pesticides and associated POPs waste have been eliminated as well as 300 tons of PCBs and PCB-contaminated equipment have been disposed of. 40 tons of obsolete pesticides under MOFAL (Ministry of Agriculture) custody were removed and eliminated.

- About 289 tons of PCB waste and PCB based equipment has been eliminated. Approximately 15 tons of PCB-contaminated mineral oil has been treated.
- Training and technical assistance on BAT/BEP for priority industrial sectors was provided for the reduction in dioxins and furans.
- About 2.98 g-TEQ/yr of PCDD/F reduction in total has been achieved.
- The technical capacity of all relevant stakeholders in central and local authorities was improved, and the national contaminated sites registration system was upgraded.
- A capacity for implementation of remediation activities has been built in line with EU regulations and standards.

Vietnam (Stockhomn Convention, 2024; UNDP, 2015)

Vietnam updated its NIP to focus on newly listed POPs which are popularly used in industries and other utilities. The updated NIP has integrated its objectives and strategies with global and national issues such as climate change, SDG goal on sustainable production and consumption (SDG 12), and has strongly linked POPs with environmental health and included gender issues; involving diversity stakeholders. The updated NIP listed 10 new POPs in addition to the initial 12 POPs.

Some of the major steps undertaken for the management of initial and new POPs include:

- Inventorization of the new 10 POPs in addition to the initial POPs. For example, POP-BDEs in electrical and electronic equipment, PBDEs in the transport sector POP-BDEs in other minor uses, and POP-BDEs contaminated sites and stockpiles. In addition, assessment and information on POPs stockpiles and contaminated sites, including 10 new POPs.
- Capacity to measure PFOS and some other PFASs has been developed in several laboratories in Vietnam.
- Some industries working in cementing, waste incineration, and steel production have participated in implementing BAT/BEP for the reduction of unintentional POPs. Some enterprises have studied and invested in the treatment of PCBs; some others

focus on development for providing services of POPs monitoring.

- Vietnam Environment Administration (VEA) established the Division of Chemical Pollution Control, environmental incidents and environmental health under the Department of Pollution Control (PCD), which has the function of consulting and assisting PCD and VEA in implementing the governmental management on chemical emission control, prevention, emergency response, and recovery of environmental incidents in accordance with laws and managing environmental health nationwide.
- Incinerators designed for domestic, industrial, hazardous, and healthcare waste treatment have been equipped with modern technology to control the release of dioxins and furans.
- Thermal desorption technology has been deployed to dispose of soil contaminated with Agent Orange/dioxin at Da Nang airport.
- In collaboration with the UNDP, Vietnam has completed the GEF-funded project "*Persistent Organic Pollutants (POPs) and Sound Harmful Chemicals Management Project*" from 2015 to 2020. The project helped to treat over 50 tons of residual pesticides and 280 tons of pesticide-contaminated soil, thereby reclaiming safe land for agriculture and creating a secure environment for the local population. In addition, almost 300 environmental monitoring centre staff received training in monitoring and analysis (United Nations Development Programme, Closing Workshop of Viet Nam POPs and Sound Harmful Chemicals Management Project, 2020).

European Union (Stockholm Convention Secretariat, 2024)

Significant progress towards the elimination of POPs has been achieved in the European Union. Manufacture and use of all POP chemicals are prohibited with some minor time-limited exemptions that are phased out over time.

Some of the major steps undertaken for POPs management are:

- The Enfiro Project, a pilot project, was undertaken for the substitution of brominated flame-retardants. This project was intended to help develop alternatives to brominated flame-retardants (including substances identified as POPs), as well as documenting lessons learnt to help others successfully transition away from POPs based substances to safer alternatives.
- The Chemicals Strategy for Sustainability, implemented in October 2020, aims to create a toxic-free environment by promoting the responsible production and use of chemicals. Its goal is to support societal goals, including the green and digital transition, while minimizing harm to the environment and future generations. The strategy envisions the EU as a strong global contender in the safe and sustainable chemicals industry. It outlines a roadmap and timeline for transforming the industry, to attract investments in safer and more sustainable products and production processes.
- The European Food Safety Authority (EFSA) developed the OpenFoodTox database for pesticide residues in food. This database provides high-level summarised data on a substance-by-substance basis including details of outcomes for specific toxicological endpoints, and hazard reference values that have been developed and then adopted by different expert committees. This includes data on the safe limits for pesticide residues in food covering a number of the POPs.
- Improvements in abatement technologies and targeted EU legislation — for instance, the Large Combustion Plant Directive, the Community Strategy for dioxins and furans (PCDDs and PCDFs) and PCBs, the Persistent Organic Pollutants Regulation and the Industrial Emissions Directive (2010/75/EU) — have contributed to marked reductions in POPs emissions in the EU since 1990 (European Environment Agency [EEA], 2024).

China and Hong Kong (Stockholm Convention Secretariat, 2024)

Since the NIP was carried out, China has undertaken steps to tackle several environmental hazards related to POPs that seriously threaten human health and safety. The production, use, import, and export of the initial intentional POPs have been stopped, and their concentrations in the environmental and biological samples have shown an overall downward trend. The emission intensity of dioxins in key sectors such as iron ore sintering, secondary non-ferrous metal smelting, and waste incineration has decreased by more than 15%. Thirdly, over 50,000 tons of POPs-containing legacy waste have been cleaned up and disposed of. The number of POPs restricted and controlled in China according to the SC and its amendments has increased from 12 to 23.

Hong Kong Special Administrative Region has made some significant progress in the management of POPs, and the existing data on emission sources, environmental contamination levels, dietary exposure and human body burden of the 23 POPs of the Stockholm Convention in Hong Kong from all available sources (relevant government databases, local academia, and open literature) has been collated and assembled in the revised NIP.

- Since 2011, regular monitoring of 21 POPs, including 9 new POPs in local marine water, sediment and biota, has been conducted.
- BAT and BEP were adopted in treating clinical waste and sewage sludge. Sewage sludge from local sewage treatment plants has been diverted to the sludge treatment facility for high-temperature incineration. All clinical waste has been collected for disposal by high-temperature incineration at the designated Chemical Waste Treatment Centre.
- The Waste Disposal Ordinance to control the disposal of PFOS/PFOSF-containing foam has been established. The Ordinance provides control over waste handling and disposal, waste import and export (including implementation of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal) and the licensing of waste collection services and waste disposal facilities.

Indonesia (SC on POPs, 2024)

Indonesia has developed its third NIP focusing on the management aspects of 30 POPs through the identification of status, data sources, resources, and activities. Some of the key steps for the management of POPs include:

- Indonesia developed a filter tool (filter inlet outlet) to capture organochlorine compounds including pesticide POPs in irrigation channels.
- A technology urea coated with activated charcoal, enriched with consortium microbes was developed to degrade organochlorine residues (POPs).
- A method for BDE analysis as a marker for microplastic samples in Indonesian waters was developed.
- Hazardous substances and POPs Information Systems have been established. Moreover, the Pesticides Information System has also been established.

Several countries, each with unique challenges, have initiated interventions to commendable progress in managing the POPs upstream, midstream and downstream. The European Union and countries like Vietnam, Egypt, China, and Indonesia have taken crucial steps towards controlling and managing old as well as new POPs. To summarize, the collective actions of all the countries, supported by international agencies and guided by shared experiences and best practices, form the cornerstone of effective POPs management.

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Chapter 9
GAP ANALYSIS

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Given the major environmental and public health issues posed by persistent organic pollutants (POPs) in India, a thorough evaluation of the current institutional, capacity, research, knowledge, policy, and technological gaps is needed. The identification of these gaps is the key focus of this chapter, especially in light of Tamil Nadu's specific status as well as the larger framework of POPs management in India. It examines the gaps in research data, regulatory frameworks, monitoring infrastructure, and disposal technologies, highlighting the necessity of stronger regulatory enforcement, increased capacity building, and innovative technical interventions. Closing these gaps is essential to developing POPs management plans that ensure greater environmental sustainability.

9.1 Institutional and capacity gaps

- In the state of Tamil Nadu, India, there is a well-established network of water monitoring stations administrated by Central Water Commission (CWC). The network covers the major river basins, and consist of baseline stations unaffected by human activities, trend stations designated to detect long term variations in water quality due to human activities, and flux/impact stations for determination of extent of pollution or geological features, and impact of pollution control measures. In these stations, hydrological and in-situ data are collected, and water samples are taken for measurements of basic water quality parameters (eg. nutrients, total dissolved solids, bacteria, and biochemical oxygen demand). In certain stations, metals and selected pesticides are measured. Some of the pesticides listed in the Stockholm convention (SC) are included in the monitored pesticides. The CWC provides a guidance document for water quality monitoring, from sampling to accreditation of laboratories performing the chemical analyses (Guidance 2017).
- Water monitoring is also performed by the Tamil Nadu Pollution Control Board (TNPCB). The TNPCB provides overviews of activities in the catchment, information about polluted river stretches, and concurrent action plans for restoration. Knowledge about sources of pollution from different types of industries and sewage wastewater plants are provided. Several pictures from sampling campaigns are provided from CWC's and TNPCB's homepages. Sampling of water is solely performed from the riverside, or by walking into the water body. Water sampling is performed by handheld simpling devices, like telescopes for bottle sampling. It is unclear if a network of boats/vessels are available that permit sampling from the deeper areas in lakes or where the flow in river is higher. It is also uncertain if equipment like grabs/corer for sediments sampling and water samplers that allows sampling at different depth or integrated sampling through the water column (from bottom to surface) are available. It is important that sampling is performed representative, in some cases sampling should be performed from the shoreline, and in other cases in the open deep water. Guidance document for sampling of POPs may also be needed, since samples may be contaminated during handling and use of improper and unclean equipment.
- TNPCB has issued several guidelines and best practices related to industry and manufacturing processes. Results from chemical analyses from the major rivers, divided into districts are provided. Typical parameters analysed are dissolved oxygen, coliforms, biological oxygen demand, and metals. Monitoring of POPs were not found at CWC's or TNPCB's homepages, except results for some selected pesticides India has ratified in the Stockholm Convention (SC). Analyses of several POPs take

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place at the Central Pollution Control Board (CPCB) in their trace organic pollutions laboratory in New Delhi. Infrastructure covering sample preparation to advanced analytical instrumentation are in place, and from the information provided the equipment cover most of the SC POPs. Matrices like soil, sediments, water, waste, and air are covered. Analyses of POPs in biota are not mentioned and may be performed by another institutions in India. The laboratory covers a substantial list of analytes, but the seven new SC POPs (chlordecone, hexabromobiphenyl, hexabromodiphenyl ether and heptabromodiphenyl ether (octa BDE), tetrabromodiphenyl ether and pentabromodiphenyl ether (penta BDE), hexabromocyclododecane (HBCDD), and hexachlorobutadiene (HCBD) ratified in 2020 in India are not listed. Knowledge used to analyse the old POPs can easily be transferred to the new ones, by skilled personal, and it can look as if laboratory instrumentation is in place for the substances as well.

- A network of river monitoring stations, covering the major catchments in Tamil Nadu are already in place. Use of this network is an excellent starting point for the establishment of monitoring stations for the SC POPs. Results from existing monitoring and knowledge about activities in the catchment will help to design efficient monitoring programmes. Access to relevant and proper sampling sites in the waterbodies are also important to perform representative sampling.
- Since CPCB is the only monitoring agency for SC POPs in India, there is a major infrastructure and capacity gap in India. During the development of the NIP on POPs, the Government of India had identified gaps to help meet the various provisions under the Convention and had identified an urgent need to strengthen and build capacity of the relevant technical institutions and the skillset of the human resources.

9.2 Research Data Gaps

- India's National Implementation Plan on POPs (NIP) has identified several **POPs contaminated sites** in the country. Though MoEF&CC has developed an action plan to remediate the contaminated sites, information is not available on the status of these POPs contaminated sites. Appropriate data is needed to develop relevant strategies for the identification of sites contaminated by chemicals listed as POPs (in Annexes A, B or C of the Convention).
- Several Indian universities and research institutions are conducting research on POPs/POPs alternatives and other related aspects. However, data on POPs management are all currently scattered. Council of Scientific and Industrial Research- National Environmental Engineering Research Institute, Nagpur (CSIR-NEERI) is the Stockholm Convention Regional Centre (SCRC) for Capacity Building and Technology Transfer across ten Asian countries including India, and could therefore be instrumental in providing a unified platform to compile all research data in one location. This will also help support NEERI's ongoing updating efforts.
- There is a lack of comprehensive and systematic monitoring programmes to track the presence, levels, and degree of contamination of specific POPs in various environmental matrices (air, water, soil, and biota) across different regions of India. The **absence of such reliable and consistent research data** triggers a rift between stakeholders and authorities over the best way to regulate POPs necessitating the strengthening of capacity building and monitoring initiatives at the local, state, and national levels.
- Accumulation of **stockpiles of old and obsolete POPs** is a big concern. Most of the Annex A Part I chemicals of the SC are banned in India. However, a limited stock of certain POPs (like aldrin and dieldrin) exists that require scientific disposal. There is little or no publicly available information on the status of how the stockpiles are stored and disposed of in an environmentally sound manner. Relevant data is needed to boost and expand research to develop new and safer methods for destroying obsolete POPs stockpiles.
- There is a **lack of public awareness** of POPs generation and their hazards (especially unintentionally produced ones). For example, DDT, a POP pesticide, although banned since 1989, is still produced and used for vector control in India and could not be replaced due to resistance and cross resistance to its available alternatives. Malathion/ synthetic pyrethroid insecticides, however, is used in place of DDT in the state of Tamil Nadu. Therefore, appropriate research coupled with awareness

generation (on linkages between DDT and malaria) is crucial. Insufficient data on public awareness and understanding of the associated risks hinders the development of targeted education and outreach programmes on POPs management.

- Owing to its contribution towards improved crop yields and crop protection, POPs pesticides have been used in agriculture in large quantities in India. It is imperative to find cost-effective, environment-friendly **alternatives** to these POPs pesticides. Extensive research is being conducted on biopesticides as a viable alternative to replace the currently used pesticides. Also, in terms of finding safer substitutes used in industrial processes, there is limited research on alternative technologies and strategies for the reduction or elimination of POPs.
- POPs such as DDT and other OCPs, are abundant in the food and environment in India that have been associated with higher **health risks** like diabetes among Indians compared with other populations (La Merrill et al., 2019). Such risks have also been noted in the migrant populations of Asian Indians living in the United States, Europe, and elsewhere (La Merrill et al., 2019). To assess such complex scenarios, comprehensive datasets are needed to assess the health impacts of POPs on human populations as well as on terrestrial/aquatic ecosystems in specific regions of India. There are also insufficient assessment studies on the routes and levels of human exposure to POPs (both short-term and long-term), especially among vulnerable populations.

9.3 Knowledge and information gaps

- New studies reveal that POPs residues, especially DDT and its metabolites, is the most frequently occurring POPs in the Indian Ocean ecosystem (Miraji et al., 2021). Such POPs are mostly found in fish putting all the interacting ecosystems at significant risk through biomagnification. Such studies are sparse, and therefore **improving POPs monitoring in oceanic environments** is necessary for the sustainability of the marine ecosystem. The INOPOL project will develop and contribute towards building a comprehensive knowledge base in this regard.
- India does not have a comprehensive and **updated national inventory of POPs** with respect to their sources, levels, and trends in varied environmental matrices (air, water, soil) and biota in different regions. Developing such an inventory is crucial for assessing the extent of POPs contamination, identifying hotspots, tracking progress, and for policy inputs for POPs reduction.
- There are **inadequate information tools** for assessing and predicting the behavior of POPs in multiple emission pathways in different environmental matrices affecting human populations through dietary, occupational, and residential exposure routes. The INOPOL project will address such complexities and offer solutions for prioritizing and implementing effective management strategies for India.
- Inadequate knowledge of the **primary sources, pathways, and quantification** of POPs, including industrial emissions, waste disposal practices, and unintentional production from various processes, is a concern.
- There is limited research on the potential interactions between **POPs and climate change**, including the influence of climate-related factors on the transport, fate, and behavior of POPs.
- **Monitoring and reporting mechanisms** for POPs are not well-established in India. This makes it challenging to assess the levels of POPs in various environmental matrices, and to report on progress made in reducing POPs emissions, all of which is needed for effective and well-informed policy decisions.

9.4 Policy and regulatory gaps

- In the EU, the preparation of effect-based limit values (environmental quality standards) for water, sediment and biota has been crucial for controlling discharges to water bodies from e.g. industry, sewage treatment plants, and agriculture. The limit values largely determine how large discharges from industries, for example, can be controlled (through emission permits), and the need to reduce their discharges (through installation of treatment plants for their waste waters). Prior to the introduction of the limit values, it was difficult for the environmental authorities to order/ demand the industry through regulation to clean the wastewater discharges and reduce their discharges. Like the EU Water Framework Directive that aims for 'good status' for all ground and surface waters (rivers, lakes, transitional waters, and coastal waters) in the EU, India may have specific standards for controlling restricted and banned POPs in all waterbodies.

- The Government of India applied the FAO Pesticides Guidelines on Storage, Labelling, and Disposal (1985), which was modified as part of the International Code of Conduct on the Distribution and Use of Pesticides. The Hazardous Wastes (Management, Handling and Transboundary Movement) Rules 2008 also mandated the environmentally sound management of POP wastes. However, the **enforcement** of these legislations has been **inadequate** as the concerned authorities had overlapping responsibilities, that led to weak implementation of these policies.
- While India has taken steps to regulate some POPs, all listed POPs are **not comprehensively regulated**. In 2020, India approved the ratification of seven chemicals listed under the SC, and the NIP is getting updated to facilitate the process of phasing out these new POPs. This gap has left room for potential environmental and health risks.
- India is actively revising and **updating its NIP**, which was first presented to the SC in 2011, as per the mandate. The NIP update requires knowledge of inventories, data collection, sampling, analysis, and coordination between several Ministries and important government agencies. Some of the barriers to updating NIP include a lack of capacity, inadequate coordination and communication amongst ministries, inaccessibility to import/export data, and concerns about data sharing. UNEP offers developing countries financial and technical support to update their NIPs. Following the ratification of 7 additional POPs, the Global Environmental Facility (GEF) has granted funds (until 2025) to India to upgrade the NIP.
- India needs robust regulations for safe handling, storage, and transportation of POPs, to prevent accidental releases into the environment. India has released the draft of the Chemical (Management and Safety) Rules (CMSR) that replaces two existing rules that is similar to the EU REACH regulation, and is expected to comprehensively address these challenges. However, there are major **chemical safety concerns**, such as human exposure, accidental environmental release and unintentional release during POPs production and POPs contamination of other waste streams. The National Centre for Vector Borne Diseases Control (NVBDCP) has developed occupational safety guidelines for handling and disposal of related POPs, but regular and strict compliance is still a major issue.
- **Enforcement** of existing regulations is challenging due to limited data, resources, capacity, and awareness. It is essential to improve compliance checks and consequences (such as penalties) for non-compliance. Adequate **financial and human resources** are needed to be allocated to implement and enforce existing regulations effectively.
- Enhancing **international cooperation** on transboundary movement and disposal of POPs is an area where improvements are needed. Implementation of SC at a global scale presents challenges such as lack of harmonization of processes and capacity in different countries as well as inventorying and curbing of primary sources of POPs. CSIR-NEERI is instrumental in addressing POPs management across ten Asian countries including India and can play a key role in environmentally sound management of POPs, and POPs-contaminated sites in these countries in the region.

9.5 Technology gaps

- Advanced **monitoring technologies** for the real-time or continuous monitoring of POPs in air, water, soil, and biota, are not in place. There is a need for cost-effective, locally suitable, and reliable continuous monitoring technologies to assess the spatial and temporal distribution of POPs.
- There is insufficient access to state-of-the-art **analytical techniques** for the detection and quantification of POPs at trace levels in India? Advanced analytical methods suitable for Indian conditions are crucial for accurate risk assessment and regulatory compliance.
- Limited technologies are available for the safe disposal and treatment of POP-containing wastes. India lags behind other countries when it comes to modern disposal technologies for certain POPs like

PCBs. Examples of these gaps include the incineration system's central control and online monitoring of the flue gas produced during the process. Improved **waste management technologies** are essential to prevent the release of POPs during disposal and to address the legacy of POP-contaminated sites. Unregulated pollution from smaller industries and improper waste handling contribute to marine and freshwater pollution. Improper waste handling is also linked to the informal waste sector practicing manual recycling, open burning, and mismanagement of electronic waste that releases large amounts of POPs.

- Effective and scalable **remediation technologies** for the cleanup of POP-contaminated sites, are not available. Development of innovative and sustainable remediation techniques is essential for addressing legacy contamination and preventing further spread.
- India faces certain challenges in carrying out the mandates of the Stockholm Convention, and lacks the necessary **equipment and technical support** for safe storage, transportation, and collecting POPs waste. To help fulfill the obligations under the Convention, it is imperative to fortify and expand the current facilities.
- Challenges exist in identifying and characterizing **new or emerging POPs**, as traditional monitoring methods may not capture all chemicals. Advanced analytical tools and techniques are needed to identify unknown or lesser-known POPs.

Summarily, this chapter highlights the current gaps and challenges related to POPs management in India, along with some insights on the project area in Tamil Nadu. The gap analysis is organised in the form of data limitations, knowledge gaps, policy and regulatory gaps, infrastructure and capacity gaps, and technological gaps. Any policy-level intervention requires a concerted effort to gather data on the production and usage of prohibited POPs. The existence of knowledge gaps highlights the necessity of developing analytical techniques that can furnish dependable data on their environmental and biological occurrences, environment fates, and potential sources. Such quantitative analysis-based monitoring provides vital information required by the regulators. The limitations around a centralized inventorization process have been noted as a major roadblock. Despite all regulatory advancements, the lack of capacity has been identified as a significant obstacle in phasing out banned POPs from India.

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Chapter 10
RECOMMENDATIONS AND WAY FORWARD

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The INOPOL project (India-Norway cooperation project on capacity building for reducing plastic and chemical pollution in India), in its second phase, supports the reduction and management of plastic and POPs pollution in Tamil Nadu, India. The project develops a comprehensive baseline on POPs pollution in Tamil Nadu by compiling existing (research-based) knowledge and data while identifying gaps within the spheres of management of POPs, thereby providing rich resources that have and will be used in project related activities. It also paves the way for effective management of POPs in other States of India. During the discussions held in June 2022, MoEF&CC and NITI Aayog (National Institution for Transforming India) expressed appreciation of the data centred approach of the INOPOL project's first phase, and raised several key knowledge needs and requests to the project team, aligning closely with the design, outcomes, and outputs of INOPOL's second phase, such as:

- **Create baseline, data collection, improved data quality***:* Provide high quality data, identify bottlenecks, and specific challenges related to implementation of policies related to control of POPs pollution in India.
- **Data management and coherence***:* Promote and establish a system for sound data management, storage, sharing, and enhancing availability and use for government and other stakeholders.
- **POPs alternatives, private sector, innovation, and technology:** Adopt new scientific developments, technical guidelines, suitability for the Indian development context, etc., sharing of technical knowledge, concrete measures and technological advances in management and implementation of the Stockholm and Basel Conventions.
- **Awareness raising, synthesising scientific data, knowledge exchange***:* Awareness raising, dissemination of knowledge to public in a comprehensible format, development, synthesis and sharing of scientific knowledge with decision-makers and regulators.

10.1 Recommendations emerging from INOPOL Project

Based on the above aspects, the key anticipated outcomes of second phase of INOPOL project summarizes the recommendations for effective management of POPs in India.

Establish local monitoring capacity on POPs.

- **Develop locally adapted monitoring strategy***:* Monitoring protocols, manuals and guidance documents will be developed for analysis of POPs that will be ready for use by government laboratories, academic institutions, and other relevant stakeholders.
- **Monitor POPs pollution in selected systems***:* Coherent systems for data collection and analysis will be developed through capacity building of relevant stakeholders in monitoring of POPs in Tamil Nadu.
- **Laboratory analysis** and advancement on POPs pollution research will be conducted.
- **Build local capacity on POPs monitoring and analysis***:* The project will focus on strengthening capacity among local government, companies, and consumers in Tamil Nadu.
- **Data management system***:* The development of appropriate data management systems will consider the significance of quality assessment and control (QA/QC), which will improve the applicability of pollution

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data. The information gathered will give government organizations crucial baseline data and the opportunity to evaluate the effectiveness of policy interventions.

Assessment of pollution sources and impacts

- **POPs inventorization of industry and waste sources***:* Such inventories will help to identify and quantify releases from and stockpiles of POPs, and eventually help decision making regarding their sound management including their disposal.
- **Hotspot assessment and prioritization***:* By identifying POPs hotspots within Tamil Nadu, the project data will support government bodies in the prioritization of efforts.
- **Review of local health and environmental impacts** will help to examine the interlinkages between exposure to POPs and local health outcomes.

Regulation, management, and socioeconomic significance

- **Analysis of existing regulations** and policy (including gaps and obstacles) will be conducted. Recommendations related to updation of the Stockholm Convention's National Implementation Plan (NIP) for India and specifications on the responsibility of the state will be provided accordingly.
- **Socio-legal study on regulatory enforcement / implementation***:* Sociolegal research concerning the implementation of regulatory policies, particularly related to social regulation will be conducted. These will include regulations that seek to advance public safety and health, environmental protection, nondiscrimination, consumer protection, etc.
- **International management experiences and best practices***:* Sharing of knowledge, experiences, and best practices on effective management of POPs between government, scientists, and civil society actors, will be established.

As the management of chemicals is directly tied to certain Sustainable Development Goals (SDGs), the INOPOL project will help towards achieving the associated targets of the goals. The targets will include 2.1 (food safety), 3.9 (reduce illnesses and deaths through contamination), 6.3 (improve water quality), 11.6 (reduce environmental impact of cities), 12.4 (chemicals management), 14.1 (reduce marine pollution), and 16.1 (protect vulnerable populations). These project objectives also directly align with the strategies, work plans, and implementation goals of the Basel Convention (1988), the Rotterdam Convention (1998), and the Stockholm Convention (2004). To address the different aspects of enhanced environment, health, and well-being, the accomplishment of these SDGs can offer a comprehensive and integrated framework for better coherence and a cross-sectoral approach towards sound POPs management across the spectrum.

10.2 Recommendations for effective management of POPs in India

The various aspects of POPs pollution in Tamil Nadu specifically and India, in general have been discussed in detail in the earlier chapters of this Baseline Report. Based on the baseline analysis conducted by the project team, a summary of the **key recommendations** for POPs management in India and Tamil Nadu in particular, are given below:

1. There is a need to analyse existing policies, identify gaps pertaining to POPs management, and suggest relevant revisions for Indian regulations. The existing regulatory gaps have been identified and appropriate steps to strengthen the regulatory provisions are being taken. India's first National Implementation Plan (NIP) on POPs was published in 2011. The second draft of the NIP is being reviewed as per the guidelines of the Stockholm Convention, and the priorities set by the National Steering Committee. The POPs inventory will also need to be updated and will therefore need to cover a significant time gap. The update of the NIP and POPs inventory of India will require bringing together all stakeholders from various levels, such as relevant ministries and departments, central and state pollution control boards, industries including MSMEs, industry associations, research, and academia, CSOs etc. This will improve the

national capacity to manage both intentionally and unintentionally produced POPs, thereby contributing to improved human health and the environment.

2. **POP pesticides** have been used in agriculture in large quantities to achieve better crop yields and meet the ever-increasing agricultural production needs in the country. India is a manufacturer and user of many pesticides that are listed or being considered by the Stockholm Convention and the Rotterdam Convention, as well as candidate POPs like chlorpyriphos. In addition to the broader chemical management portfolio, addressing this challenge on POPs pesticides will require concerted efforts and a comprehensive strategy. It is crucial for India to find cost-effective environment-friendly alternatives like bio-pesticides (to replace currently used POPs) through extensive research and development.
3. A thorough **monitoring system** should be in place to be able to track the presence, levels, and degree of pollution of certain POPs in several environmental matrices (air, water, soil, and biota) throughout different regions of India. This will help produce consistent and trustworthy research data on POPs. Relevant data on obsolete POPs are also required (in addition to data on emergent and current POPs) to advance and broaden research into the development of safer and more innovative techniques for eliminating these stockpiles of obsolete POPs.
4. To assess the complex scenarios related to the routes and levels of human exposure of POPs on different species and in varied ecosystems, **comprehensive research** is needed to assess the health impacts of POPs on human populations as well as source identification and apportionment in specific regions of India, especially among vulnerable populations.
5. India lacks proper channelization of relevant expertise and capacity for analysis of **new POPs**, creating a major barrier for the development of a POPs inventory. While India had received funding from the Global Environment Facility (GEF) and assistance from implementing agencies for the development of the first NIP, the second NIP will cover more chemicals as it will include old as well as new POPs. The efficient management of new POPs would require better coordination between key stakeholders (both government and non-government) and coordinated efforts during its implementation.
6. There is a significant difference between India and other advanced countries when it comes to **waste disposal technologies** of certain POPs such as dioxin-like polychlorinated biphenyls (PCBs), dioxins, and furans. There are several challenges in carrying out the Convention's responsibility as well. Furthermore, India lacks the necessary equipment and technical support for the collection, transportation, and secure storage of PCBs. To facilitate work toward meeting the criteria under the Convention, it is imperative that capacity be built, and the facilities be strengthened of the relevant technical institutions and human resources.
7. The development of targeted education and outreach programmes on POPs management is imperative. Appropriate **awareness generation programmes** on the linkages between POPs and human health (pertaining to the occurrences of diseases) is crucial. Such awareness generation programmes should focus on disseminating public information, education, communications, and encourage public participation for mitigation of risks associated with POPs accumulated in India (for example, stockpiles of obsolete pesticides). The key stakeholders must include NGOs, CSOs (civil society organisations), subject-matter experts, representatives of governmental authorities, international organisations, and social/mass media outlets.

NOTES

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