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INOPOL

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

BASELINE REPORT

PERSISTENT ORGANIC POLLUTANTS IN INDIA

Norwegian Embassy New Delhi | NIVA Norwegian Institute for Water Research | MU GAMMA Consultants Pvt. Ltd | SRM

INOPOL (2021) Baseline Report on Persistent Organic Pollutants in India

Acknowledgements

This report is a joint effort by the **Norwegian Institute for Water Research (NIVA)**, Norway's leading institute for fundamental and applied research on marine and freshwaters; **Mu Gamma Consultants Pvt Ltd (MGC)**, which works towards environmental-friendly solutions in promoting green development across India; **SRM Institute of Science & Technology (SRMIST),** a private deemed university at the forefront of breakthrough research and innovation in environmental sciences and other areas; and **Toxics Link (TL)**, an NGO dedicated to bringing toxic-related information into the public domain with unique expertise in the areas of hazardous, medical and municipal wastes.

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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FOREWORD

Hans Jacob Frydenlund

Ambassador

The Royal Norwegian Embassy in New Delhi

Over two years have passed since India and Norway established a Joint Marine Pollution Initiative to tackle and prevent pollution from both land-based and offshore activities in India, in line with SDG 14 – Life Below Water. This bilateral cooperation blossoms by taking advantage of our nations' respective strengths in marine research, waste management, technology, environmental pollution and human health, to learn from one another and implement best practices for sustainable development.

The Royal Norwegian Embassy in New Delhi is pleased to support the launch of the INOPOL project's comprehensive baseline report on Persistent Organic Pollutants (POPs) pollution in India. The report highlights the important cooperation between India and Norway towards a sustainable blue economy; a joint effort which is continuously expanding in the fields of climate change, environmental research and ocean health.

The common challenges of marine litter and pollution demands global solutions and local actions. Through high quality research and capacity building the two countries collaboratively accelerate the implementation of common responsibilities under multilateral platforms such as the Stockholm Convention on POPs. The close bilateral dialogue and transdisciplinary relationships developed as part of the INOPOL project will also be key when we continue to explore the feasibility of establishing a new global agreement to combat plastic pollution.

At the Embassy, we are delighted to read the extensive baseline research conducted under the INOPOL project, which is a repository of knowledge. The report bridges important knowledge gaps on POPs pollution in the State of Gujarat and contributes to strengthen capacity to prevent and mitigate associated environmental threats, which in turn will benefit both policy makers and the wider public.

FOREWORD

Dr. Thorjørn Larssen

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Plastic and chemical pollution are key threats to the sustainability of our societies and environment. The interlinked challenge of plastic pollution and persistent organic pollution requires diverse solutions that are local, national and global in scope. One important measure is to identify and tackle the sources of plastic waste and chemical pollution. This is particularly important in countries lacking efficient monitoring systems, waste management infrastructure and capacity to manage plastic waste at pollution hotspots.

The INOPOL project is part of the India-Norway Marine Pollution Initiative, which is a bilateral collaboration aimed at combatting marine pollution. An important component in this strategy is to improve societal wellbeing as part of achieving the sustainable development goals (SDGs), in addition to preventing and significantly reducing marine pollution from land-based activities (SDG target 14.1). At NIVA, we are privileged to be working with leading Indian partner organizations and stakeholders to co-produce this important knowledge base.

NIVAs strategy towards 2030 aims to use our expertise in multidisciplinary water research to find solutions to environmental challenges at the local and national levels. International cooperation projects such as INOPOL are important elements in this strategy. We are delighted to share this report which provides a starting point for developing knowledge and capacity to reduce plastic and chemical pollution in India, the region and beyond.

The chapters of this report provide important insights into the Indian policy environment, pollution levels, existing monitoring practices, related health and environmental impacts, best practices and ways forward. This science-based knowledge forms the foundation of developing strategies and action plans to strengthen local and regional capacity towards significantly reducing the environmental and human threats posed by plastic and chemical pollution.

The preparation of this report would not have been possible without the contributions from many highly committed people. On behalf of NIVA, I want to thank the Royal Norwegian Embassy in New Delhi for support and the entire project team for their great efforts.

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List of ABBREVIATIONS AND ACRONYMS

μECD	Microelectron capture detection
ABS	Acrylonitrile-butadiene-styrene
Ag	Silver
Al	Aluminum
AMAP	Arctic Monitoring and Assessment Programme
APCD	Air Pollution Control Device
BAT	Best Available Technology
BDE	Bromodiphenyl ether
BEP	Best Environmental Practices
BHC	Benzene Hexachloride
BOD	Biological Oxygen Demand
BPA	Bisphenol A
BREFs	Best Available Techniques Reference documents
CBA	Cost-benefit analysis
CETP	Common Effluent Treatment Plant
CHE	Collaborative on Health and Environment
CIB&RC	Central Insecticides Board and Registration Committee
CIEL	Center for International Environmental Law
CIPET	Central Institute of Petrochemicals Engineering & Technology
CLRTAP	Convention on Long-Range Transboundary Air Pollutants
COD	Chemical Oxygen Demand
COP	Conference of Parties
CP	Chlorinated Paraffin
CPA	Critically Polluted Area
CPCB	Central Pollution Control Board
CPRI	Central Power Research Institute
CSIR	Council of Scientific and Industrial Research
Cu	Copper
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DEHA	Diethylhydroxylamine
DEHP	Di(2- ethylhexyl) phthalate
DLLME	Dispersive Liquid–Liquid Micro Extraction
EC	European Commission
ECD	Electron Capture Detector
ECHA	European Chemicals Agency
EDC	Endocrine-Disrupting Chemical
EIPPCB	European Integrated Pollution Prevention and Control Bureau
EPA	a) Environmental Protection Act (India) b) Environmental Protection Agency
EPS	Expanded polystyrene
ESI	Electrospray ionization
ESM	Environmentally Sound Management
EU	European Union
GC	Gas chromatography
GDP	Gross Domestic Product

GEC	Gujarat Ecological Commission
GEF	Global Environment Facility
GIDC	Gujarat Industrial Development Corporation
GoI	Government of India
GPCB	Gujarat Pollution Control Board
GSDP	Gross State Domestic Product
HBB	Hexabromobiphenyl
HBCDD	Hexabromocyclododecane
HCB	Hexachlorobenzene
HCBD	Hexachlorobutadiene
HCH	Hexachlorocyclohexane
HIL	Hindustan Insecticides Limited
HIPS	High impact polystyrene
HPLC	High performance liquid chromatography
HRMS	High-resolution mass spectrometry
IARC	International Agency for Research on Cancer
IIT	Indian Institute of Technology
I-NGO	International Non-Governmental Organization
INOPOL	India-Norway cooperation project on capacity building for reducing plastic and chemical pollution in India
IPPC Bureau	Integrated Pollution Prevention and Control Bureau
LC	Liquid chromatography
LLE	Liquid–Liquid Extraction
LRAT	Long-range atmospheric transport
MAE	Microwave-Assisted Extraction
MGC	Mu Gamma Consultants Pvt. Ltd.
MHF&W	Ministry of Health and Family Welfare (Government of India)
MMFM	Multimedia Fate Model
Mn	Manganese
MoCF	Ministry of Chemicals and Fertilizers (Government of India)
MoEF&CC	Ministry of Environment, Forest and Climate Change (Government of India)
MoES	Ministry of Earth Sciences (Government of India)
MoSPI	Ministry of Statistics and Programme Implementation (Government of India)
MP	Microplastic
MS	Mass spectrometry
MSME	Ministry of Micro, Small & Medium Enterprises (Government of India)
NCL	National Chemical Laboratory
NEERI	National Environmental Engineering Research Institute
NGO	Non-Governmental Organization
NGT	National Green Tribunal
NH3-N	Ammoniacal nitrogen
NIIST	National Institute for Interdisciplinary Science and Technology
NIP	National Implementation Plan
NIVA	Norwegian Institute for Water Research
NRTOL	National Reference Trace Organics Laboratory
NSC	National Steering Committee
NVBDCP	National Vector Borne Disease Control Programme
OCP	Organochlorine pesticide
OECD	Organisation for Economic Co-operation and Development
PAE	Phthalate Ester
PAH	Polycyclic Aromatic Hydrocarbon
PAS	Passive air sampler
Pb	Iron
PBB	Polybromobiphenyls
PBDEs	Polybrominated diphenyl ethers
PBT	a) Persistent, bio accumulative and toxic b) Polybutylene terephthalate
PCB	Polychlorinated Biphenyl
PCDD/Fs	Polychlorinated dibenzo dioxins/furans
PCNs	Polychlorinated naphthalenes
PCP	Pentachlorophenol

PeCB	Pentachlorobenzene
PFASs	Perfluoroalkyl Sulfonate Substances
PFHxS	Perfluorohexane sulfonate
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PIB	Press Information Bureau
PIC	Prior Informed Consent
PMG	Project Management Group
POPRC	Persistent Organic Pollutants Review Committee
POPs	Persistent Organic Pollutants
PPP	Purchasing power parity
PUF-PAS	Polyurethane foam disk passive air samplers
QTOF	Quadrupole Time of Flight
QuEChERS	Quick, Easy, Cheap, Effective, Rugged, and Safe
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RF2	Phenolic resin
RPA	Risk & Policy Analysis
SACEP	South Asia Co-operative Environment Programme
SAICM	Strategic Approach to International Chemicals Management
SAS	South Asian Seas
SC	Stockholm Convention
SCCPs	Short-chain chlorinated paraffins
SCRC	Stockholm Convention Regional Centre
SCRC	Stockholm Convention Regional Centre
SDGs	Sustainable Development Goals
SMC	Surat Municipal Corporation
SME	Small and Medium Enterprise
SOPs	Standard operating procedures
SPCB	State Pollution Control Board
SPE	Solid Phase Extraction
SRM	SRM Institute of Science & Technology
STP	Sewage Treatment Plant
SUDA	Surat Urban Development Authority
SVHC	Substances of Very High Concern
SWMR	Solid Waste Management Rules
TCDD	Tetrachlorodibenzo para dioxin
TERI	The Energy and Resources Institute
TL	Toxics Link
UAE	Ultrasound assisted extraction
UHPLC	Ultra-high performance liquid chromatography
ULBs	Urban Local Bodies
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
USA	United States of America
UT	Union Territory
VIE	Vapi Industrial Estate
VOC	Volatile Organic Compound
vPvB	very Persistent and very Bio-accumulative
WEDO	Women's Environment and Development Organization
WEEE	Waste Electric and Electronic Equipment
WHO	Word Health Organisation
WQM	Water Quality Modelling
WTP	Willingness to Pay
WWTP	Wastewater Treatment Plant
XPS	Extruded polystyrene
Zn	Zinc

Executive **SUMMARY**

This executive summary for the 'INOPOL Baseline Report on Persistent Organic Pollutants (POPs)' introduces key themes covered in each chapter of the full report, including the INOPOL project background, description of catchment areas, regulations and policy status. It also presents the status of pollution in Gujarat State due to POPs, existing monitoring activities and methodologies, health and environmental impacts of POPs (including the seven new POPs), international and Indian best practices of management of POPs, gaps and a way forward.

The India-Norway cooperation project on capacity building for reducing plastic and chemical pollution in India (INOPOL) aims to prevent and substantially reduce the scope of marine litter from sources in the catchment areas of rivers Tapi (Tapti) and Daman Ganga along the cities of Surat and Vapi in Gujarat State. These rivers are highly affected by petrochemical and industrial activities and are major receivers and transport routes for land-based plastic pollution. Tapi river flows through the metro-city of Surat, which has experienced significant economic growth. Vapi is situated near the banks of Daman Ganga and is the largest industrial area in Gujarat, dominated by chemical and paper industries. **Chapters 1 and 2** detail the project background and justifies the pilot catchment areas.

Industrial pollution and improper waste handling are major drivers of marine litter and microplastics, where a potentially significant side effect is increasing loads of POPs in the environment. Open burning of plastic waste and mismanagement of electronic waste results in releases of POPs. The ship recycling industry is also a potential source of POPs emissions. **Chapter 3** encapsulates the status of POPs pollution in the catchment area of rivers Tapi and Daman Ganga. It also provides a snapshot of the use, emission and release of POPs into environment. India ratified the Stockholm Convention (SC) on POPs in 2006, which aims to reduce and eliminate the release of POPs. Although India recently updated its regulations to include seven new POPs, lack of capacity remains a major obstacle in the development of implementation plans and strategies for phasing out hazardous chemicals in the country.

At present, the information on the seven new POPs (Chlordecone, Hexabromobiphenyl, Commercial octa-BDE, Commercial penta-BDE, Pentachlorobenzene, Hexabromocyclododecane and Hexachlorobutadiene) is limited, as India has not created any inventory on these chemicals and information is largely available from secondary sources. Most of these chemicals are industrial chemicals. For example, evidence shows that industries in Gujarat are involved in the production of POPs, such as hexabromobiphenyl, hexachlorobutadiene, and decabromodiphenyl ether. As Gujarat is a hub for chemical-, textile-, and automobile industries, there is a high probability of stockpiles of these industrial chemicals. Automobile industries in Vapi and Surat use Perfluorooctane Sulfonate (PFOS), Perfluorohexane sulfonic acid (PFHxS) and brominated flame retardants (BFRs), which are important raw materials during production. There is an urgent need for the identification of cost-effective monitoring techniques, mapping and clean-up programs for contaminated sites. The regulatory framework, policies and programs in chemical waste management, with specific emphasis on POPs is presented in **Chapter 4**. It provides an overview of environmental governance in India with regard to chemical management and more specifically to POPs. It also discusses India's National Implementation Plan for management of POPs.

The interlinkages between plastic and POPs needs to be studied to derive potential solutions for management of both pollutants. Research on environmental contamination of POPs and its related human health impacts is scarce. **Chapter 5** focuses on the toxic emissions of POPs from plastic production and inadequate plastic waste management, which pose serious threats to the ecosystem and human health such as disrupting the endocrine system in humans and affecting ecosystem and organism health. Considering the limited research for plastic-POPs interlinkages, the INOPOL project will provide a comprehensive and holistic view of both types of pollutants.

The major industrial areas in Gujarat include the large industrial estates of Ankleshwar, Nandesari and Vapi, which are industrial and pollution hotspots. **Chapter 6** presents hotspots of POPs pollution in the catchment areas of rivers Tapi and Daman Ganga in the cities of Surat and Vapi. There is a wide gap in data on the inventories and the current levels of POPs in the environment, and the extent of contamination for many notified compounds remain unknown. The baseline report provides a repository for information related to Hexachlorocyclohexanes (HCHs), Polybrominated diphenyl ethers (PBDEs), Dioxins /Furans and Short-chain chlorinated paraffins (SCCPs), and their current scenario at the national level.

Chemical pollution has traditionally been regarded as the result of intentional and unintentional point source emissions from industry, agriculture and waste disposal. However, diffuse pollution sources in the landscape as well as contaminant storage and remobilization from soils and sediments add enormous complexity to the task of assessing exposure and risk from both experimental and theoretical points of view. Developing tools for understanding and predicting the behaviour of chemical contaminants with multiple emission pathways and complex environmental behaviour is an essential step for prioritizing and implementing effective pollution management strategies. Oceans are crucial players for the global cycling of POPs and the net effect of POPs cycling in the environment is their transport from warmer regions to colder places like the Arctic or mountain areas, where atmospheric POPs present in the vapour/particulate phase condense/are removed by wet deposition. **Chapter 7** presents an overview of the transport of POPs from Source to Sea.

The development of analytical methods for the seven new POPs is needed to provide reliable data for their environmental and biological occurrences, and to investigate their distribution, temporal and spatial trends, environment fates and potential sources. Such quantitative analysis-based monitoring provides regulators with vital information. The environmental monitoring techniques of targeted POPs (**Chapter 8**) gives a detailed overview of the sampling techniques of air, water, soil, sediments and biota. This chapter also discusses the different extraction techniques and further deliberated on instrumental analysis of new POPs.

POPs are known to cause detrimental environmental impacts. Over the last three decades, a number of studies have linked POPs exposures to declines, diseases, or abnormalities in a number of species including fish, birds, and mammals. The environmental and health impacts of POPs (such as the risk of cancer) has been discussed in **Chapter 9**. Prudent economic analyses of regulatory measures for these substances requires consideration of related external damages. A cost-benefit analysis (CBA) provides a standard framework for comparing the socio-economic and environmental impacts of production processes that causes emissions.

The Stockholm Convention is the most important international regulatory framework for the management of POPs. Other international governance initiatives also cater to the management of chemicals and POPs, such as the Basel Convention, Rotterdam Convention, Strategic Approach to International Chemicals Management (SAICM) and the European Commission's REACH regulation (Registration, Evaluation, Authorization and Restriction). For the management of POPs, there is a need to implement Best Available Technology (BAT) and Best Environmental Practices (BEP) by adopting appropriate prevention and release reduction measures including the promotion of alternatives (**Chapter 10**).

The Union Cabinet on India approved ratification of the seven new POPs on the 7th October 2020. The list of these seven identified POPs is part of the earlier mentioned 16 new chemicals banned by the Stockholm Convention. **Chapter 11** deals with a compilation of information gathered from the Stockholm Convention (SC) documents on the seven new POPs, and presents information about its use, emission sources, presence in waste and routes of releases.

Despite emerging research and growing attention, limitations and challenges exist within monitoring, assessment methodologies, and capacity to measure and manage POPs in the environment. The report discusses these in detail with an emphasis on the project case study areas in India (**Chapter 12**). The INOPOL project aims to address these gaps by providing science-based approaches, knowledge exchange, training and policy input to strengthen local and national capacity to ultimately mitigate the environmental threats posed by pollution due to POPs.

The final chapter (**Chapter 13**) focuses on how the INOPOL project will make result-oriented contributions to reduce pollution in India due to POPs. The comprehensive baseline report for land-based sources of POPs provides a strong knowledge base for upcoming project activities. The baseline will be followed and completed by the development of a data collection strategy, a sampling and analysis strategy, a monitoring strategy for POPs, policy notes and an action plan for new POPs for Gujarat State, and capacity building and training programs for key stakeholder groups, such as policy makers, industry, technical experts, laboratory personnel, community groups and civil society.

CHAPTER 1
PROJECT BACKGROUND

The report presents the baseline assessment of the India-Norway cooperation project on capacity building for reducing plastic and chemical pollution in India (INOPOL). The report details analysis of the current situation to identify the starting point for the project, a benchmark and a reference point for the assessment of project outcomes. The information provided includes the description of the study sites, including socio and economic context, regulation and policy status, pollution levels, existing monitoring activities and data, knowledge about health and environmental impact, and best management practices. Furthermore, the report assesses the existing data gaps that the INOPOL project will contribute to fill. There are numerous ongoing activities and initiatives in India and the context is rapidly evolving, hence, the present report represents a snapshot of the situation, building on the data available to the authors at the time of writing this report.

Encompassing two major and highly interlinked pollution issues: plastic and hazardous chemicals, the baseline will be offered in two different reports, of which the present addresses chemical pollution, with focus on Persistent Organic Pollutants (POPs).

1.1. INOPOL Project at a glance

The India-Norway cooperation project on capacity building for reducing plastic and chemical pollution in India (INOPOL) is a collaboration project between Indian and Norwegian institutions with the objective to build knowledge and capacity to tackle plastic

The Key features of the INOPOL Project are:

Time frame:	January 2019- June 2022
Funding:	The Norwegian Ministry of Foreign Affairs
Program:	Norwegian Development Assistance Program Against Marine Litter and Microplastics, India-Norway Marine Pollution
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

and chemical pollution from major sources within industry, public sector, and civil society in India.

A stronger scientific knowledge base will support India's ambitious domestic targets to reduce plastic releases and enhance its efforts to achieve international commitments, such as the UN Clean Seas, the Basel Convention on hazardous waste and the implementation of the Stockholm Convention on Persistent Organic Pollutants (POPs).

To combat marine litter and microplastics, the Norwegian government in 2018, launched a new development program "the Norwegian development program to combat marine litter and microplastics". The main objective of the entire program is to "prevent and greatly reduce the extent of marine litter from large sources in developing countries", with a focus on populous and economically fast-growing countries in Asia. INOPOL was granted funding support under the program in 2019 to develop coherent systems for data collection and analysis in India.

The INOPOL project was formally launched by the Norwegian Minister of Climate and the Environment, Mr. Sveinung Rotevatn, at the Sabarmati Riverfront, Ahmedabad, in February 17, 2020. Project preparations and inception work commenced in 2019 and will continue until the end of June 2022.

Building on the project teams' strong experience within environmental monitoring and management of POPs, micro and macro plastics, the key goals include:

1. To establish baselines on use and release
2. To strengthen monitoring capacity and standardization techniques
3. To assess social drivers and impacts, and identify sustainable solutions
4. To develop sound monitoring and management tools

The final combined products of these efforts are a) sector-specific road maps for reduced marine-litter and microplastic pollution (land-based), and b) a basis for a State-implementation plan on POPs.

The INOPOL project is led by the Norwegian Institute for Water Research (NIVA) (Project Lead), in close collaboration with The Energy and Resources Institute (TERI) and Mu Gamma Consultants Pvt. Ltd.

The overall project implementation will be done in close cooperation between the project partners with significant outreach, capacity building activities (internal and external), dissemination and awareness raising with industry, government and civil society.

1.2. Objectives and outcomes

INOPOL aims to address the highly interlinked challenges of marine litter, microplastics and Persistent Organic Pollutants (POPs). The main objective is to build knowledge and capacity to tackle and reduce plastic and chemical pollution from important sources within industry, public sector, and civil society in India. With a geographic focus on Gujarat State, the project has two main goals:

1. To enhance capacity to reduce marine litter and microplastics pollution
2. To enhance capacity to reduce release of persistent organic pollutants (POPs)

By applying a knowledge-based scientific approach INOPOL will investigate land-based sources, social and economic drivers, river fluxes and ocean input of plastic and POPs pollution. Based on these project outcomes, the project will identify effective reduction and control measures. The project seeks to synergize with and enhance ongoing efforts by key stakeholders (e.g. ministries, scientific institutions, NGO's) to reduce pollution in the State of Gujarat.

The INOPOL project will contribute to the outcome of reduced releases of POPs in India, starting by the development of a baseline for use and release of POPs in manufacturing, production, as well as in use. The data will be collected by carrying out an inventorization of sources and mapping current use and release. Subsequently the information compiled will be supported by environmental measurements, activities that will be an integrated part of the local capacity building on monitoring and analysis. The outcomes of the inventorization and the monitoring will feed into catchment flux models to understand the fate and transport of the POPs once entering the environment. Building on this the project will develop tools and knowledge that will facilitate and contribute to strengthen chemical management in the region. Moreover, the project will assess various management options, including various best practices, to understand their potential social and economic impact and relevance for India. The outcomes will accumulate in an action plan for reducing use and release of POPs in Gujarat.

In summary, the project has the following outcomes:

1. Increased capacity to reduce marine litter and microplastics pollution in Gujarat State
    a) Baseline for land-based sources of marine litter and microplastics established
    b) Monitoring capacity strengthened
    c) Tools for management of marine litter and microplastics developed
    d) Assessment of societal drivers and socioeconomic and societal impacts of measures
    e) Capacity building and training carried out and awareness raised
    f) Plastic Waste Management Strategy Report: Gujarat
2. Increased capacity to reduce releases of POPs in India, by supporting implementation of SC
    a) Baseline for use and release established, incl. links to plastic pollution
    b) Monitoring capacity strengthened
    c) Tools for management of POPs established
    d) Enhanced basis for policy and management, social/economic impacts and best practices
    e) Capacity building and training carried out and awareness raised
    f) Action plan for reducing use and release of new POPs in Gujarat

The project will develop a pilot for Gujarat State that subsequently may be used to scale up of efforts at national level. Key goals and ambitions are the building of knowledge and capacity of different groups of stakeholders, experts, and civil society to help reduce the releases and impacts of plastic pollution and the 'new' POPs listed under the SC and developed by the Government of India.

1.3. Project Stakeholders

The INOPOL project builds on well-established, long-term and successful collaborations between Norwegian and Indian institutions.

The major stakeholders have been divided into three different main groups and will be targeted separately:

1. Policy makers, industry, and enterprise managers, which may need to take action against plastic pollution and new POPs and therefore must have a strengthened knowledge about different aspects of plastic and POPs pollution. *I.e. SPCB, CPCB, MoEFCC, MoES, ULBs, industry associations and specific enterprises.*
2. Technical experts involved in the project or working with related projects. Particularly important are laboratory personnel (especially in SPCB and CPCB laboratories), who must have sufficient knowledge about the challenges in plastic and POPs analyses, and experts working with environmental assessments, who need sufficient knowledge to evaluate the extent of a given problem (e.g. a contaminated site or an emission source). *I.e. SPCB, CPCB, MoEFCC, ULBs, NEERI, IIT Gandhinagar, research institutes, universities and private laboratories*
3. The community who will benefit immensely from science-based general and balanced information about plastic pollution, POPs and related concerns. *I.e. NGOs, informal workers and civil society in general.*

Furthermore, stakeholders like NGOs, informal workers, government, industry and civil society are important to get hold on necessary information to map the plastic waste network, as well as to identify social and economic drivers, impacts and sustainable solutions.

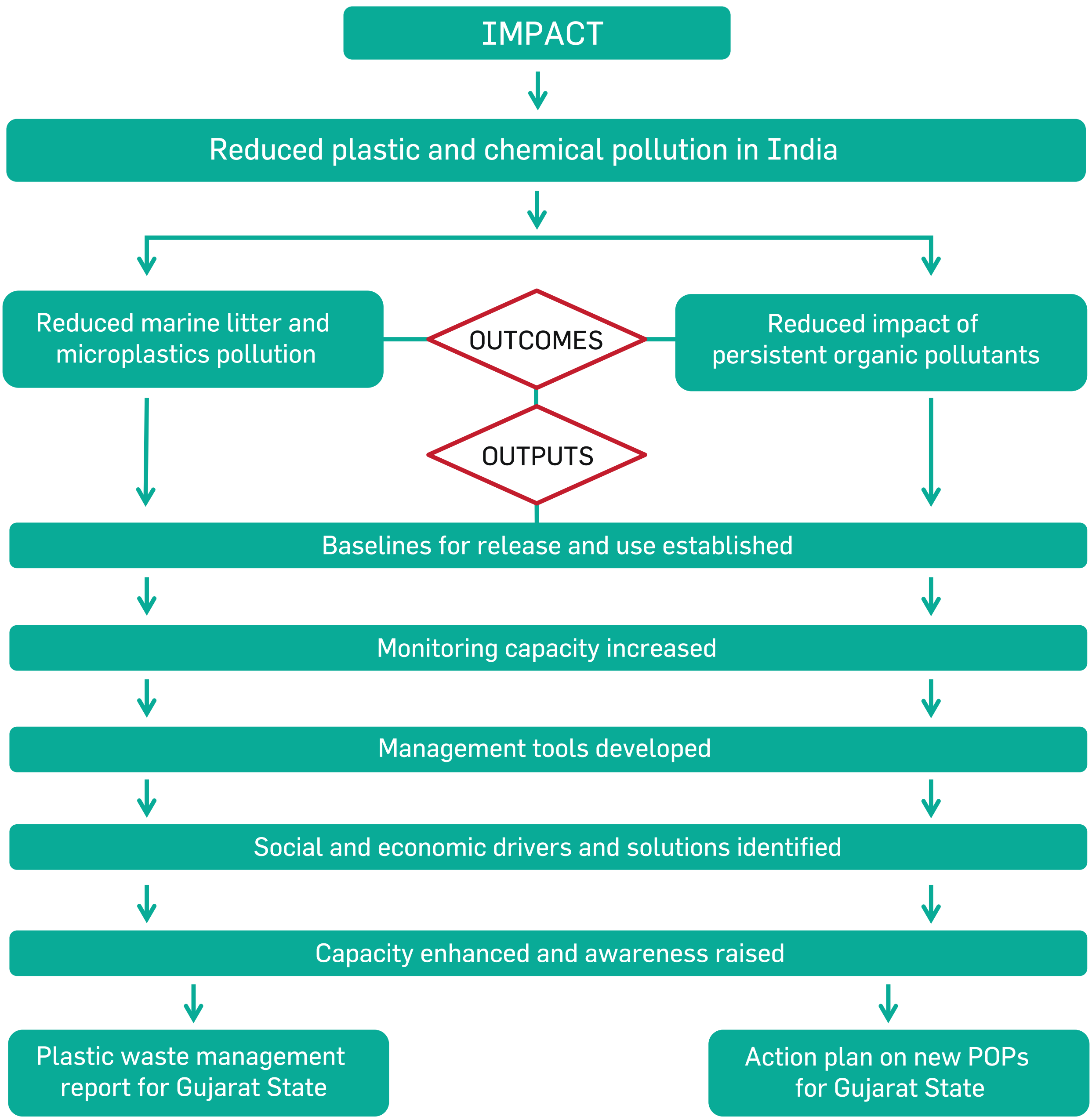

Figure 1.1 An overview of the INOPOL project's goal hierarchy

Chapter 2

DESCRIPTION OF PILOT CATCHMENT AREAS

2.1 Background: Chemical Industries in India and Gujarat State

India ranks sixth in the world and third in Asia in the chemicals and petrochemicals sector. The country ranks 14th in export and 8th in import of chemicals (excluding pharmaceuticals products) globally. The market size of the chemical sector in India for the year 2018-2019 was approximately US$ 178 billion, which is expected to reach US$ 304 billion by 2024-2025 at an annual growth rate of 9.3%. The growth is expected to be determined by rising demand in end-use segments for 'specialty chemicals' and for petrochemicals intermediates. The chemical industry is a key component of the Indian economy, accounting for about 2% of the total GDP and 15% of the manufacturing GDP (CII, n.d.).

The current per capita consumption of chemical products in India is about one-tenth of the world average. The Department of Chemicals and Petrochemicals, Government of India has anticipated that the demand for chemical products is projected to grow at 9% p.a. between 2020 and 2025, and is pegged at 1.2 X GDP growths. The Indian chemical industry is estimated to be valued at $163 Bn in 2017 (against the global estimate of $4.7 Tn), and contributes 3.4% to the global chemical industry.

Gujarat State on the western coast of India with a coastline of 1,600 km is the fifth largest Indian state by area and the ninth largest state by population. The economy of Gujarat with a Gross State Domestic Product (GSDP) of Rs 15.02 lakh crore (US$210 billion) and has the country's 11th-highest GSDP per capita of Rs.197,000 (US$2,800) (MoSPI Report, 2020). Gujarat ranked #3 in the National Council of Applied Economic Research's State Investment Potential Index (N-SIPI) in 2018.

Gujarat accounts for 51% of the production of major chemicals in India, including organic chemicals, inorganic chemicals, alkali, pesticides and dyes and dyestuffs (CEW India, n.d). Recently, the Government of India has announced the establishment of a Petroleum-, a Chemical- and a Petrochemical Investment Region at Dahej, Bharuch District in Gujarat covering an area of 452.98 sq.km area. The world's largest ship-breaking yard is in Bhavnagar at Alang. As per the Government of Gujarat, there are about 500 large- and medium-scale industrial units of Chemical and Petrochemical industries, nearly 16,000 small-scale industry units and other factory units. The State has taken the lead to promote environment-friendly practices for effluent treatment of industrial plants, 28 of which are operational plants and six are proposed (Government of Gujarat, 2016-2017). It has developed industrial estates in clusters. South Gujarat alone has 132 clusters.

2.2 Description of Project Study areas

To execute the different project activities and develop a knowledge base for Persistent Organic Pollutants (POPs) and plastic pollution issues, two catchment areas in the State of Gujarat are selected – Tapi river

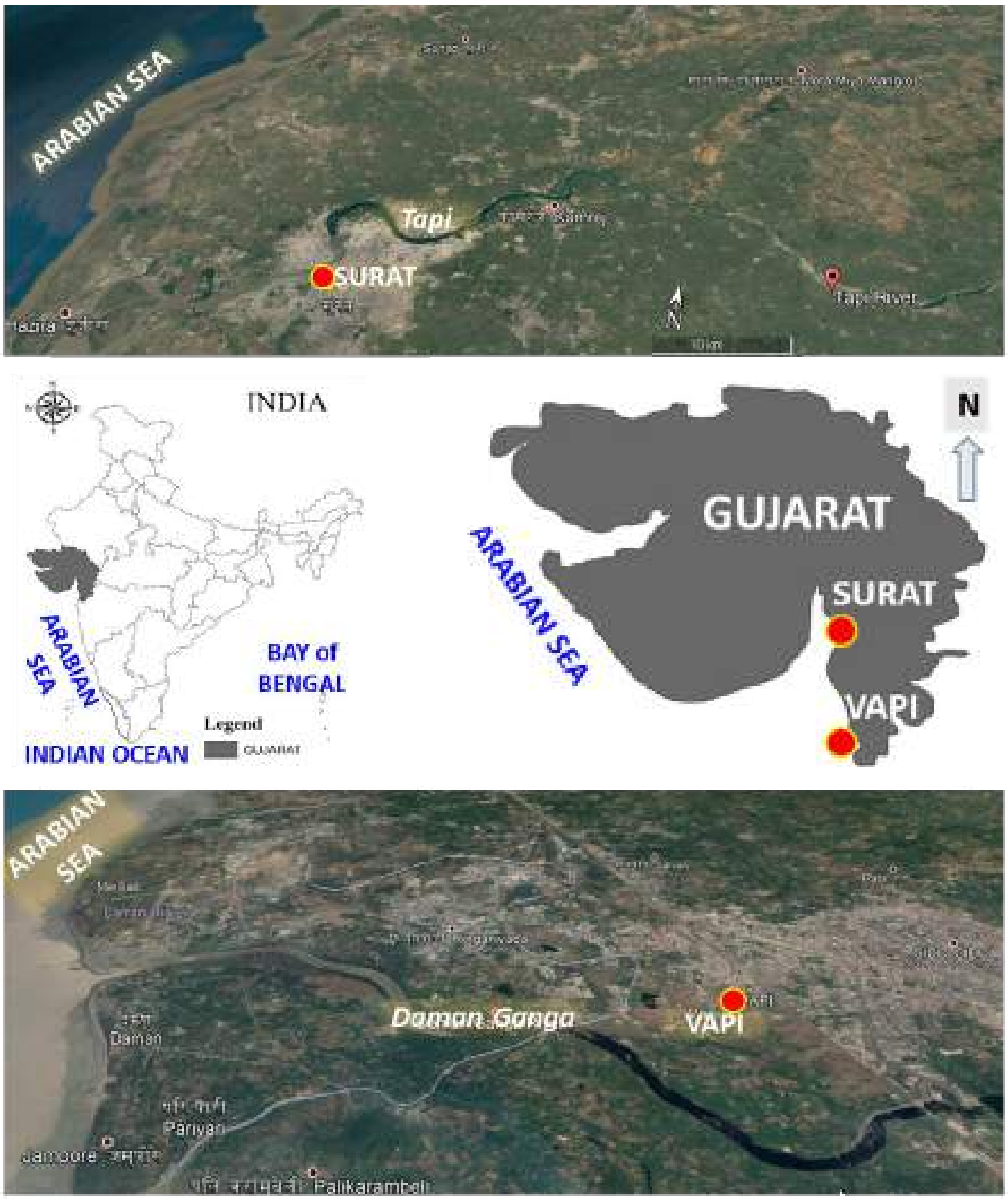

Figure 2.1: Project sites in Gujarat

catchment with the city of Surat as the main urban industrial centre and Daman Ganga catchment with Vapi as the main industrial centre. Both these rivers drain into the Arabian Sea. The case study areas have been selected on account of their socio-economic, physical and ecological profiles making these areas hot-spots for marine pollution.

2.2.1 Surat

The city of Surat is located along the coast in Gujarat between the latitudes 21.112° North and longitude of 72.814° East and spreads over an area of 326.515 km^2 (Surat Urban Development Authority, 2017). The rivers Tapi and Mindhola flow through the city, both of which drain into The Gulf

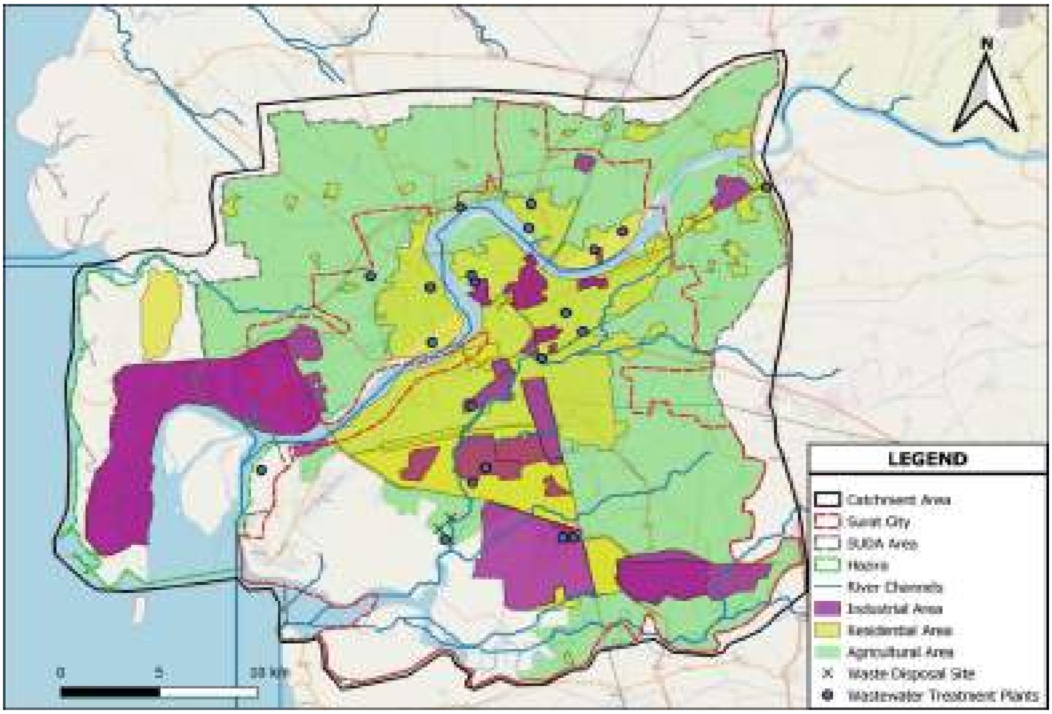

Figure 2.2: Surat urban agglomeration

of Khambat (Cambay). Surat is a low-lying city with an elevation of 13 m above sea level. Surat experiences a tropical climate with an average annual rainfall of approximately 60 inches (1525 mm). As per the 2011 census, the population of Surat was approximately 4.6 million, with a population density of 13,680 people per km^2. Surat Municipal Corporation (SMC) is the administrative body in the city. Surat is a highly industrialized city with an abundance of diamond and textiles industries. The city has an estimated GDP of $59.8 billion – 9th largest amongst Indian cities. Surat urban agglomeration consists of SMC area, SUDA area and the town of Hazira (extended SUDA area). Surat urban agglomeration is as shown in Figure 2.2.

The figure shows that the area under SMC is densely populated. This is within the catchment of rivers Tapi and Mindhola. The catchment also consists of mangroves that go by the name Hazira Mangroves. The details of the Surat catchment are tabulated in Table 2.1.

Table 2.1: *Surat catchment details*

Details	Surat catchment
Name of river flowing	Tapi
Length of river system	724 km[1]
Area of catchment	715 sq.km[2]
Number of basins within catchment	1 (Lower Tapi Basin)[3]
Number of inhabitants	4,805,101[2]
Number of urban clusters	5[2]
Number of industries	41,300[4] (approx.)
Number of WWTPs/CETPs	5[2]

[1] (Central Water Commission, 2014); [2] (Surat Urban Development Authority, 2017); [3] (Gundaliya, 2016); [4] (MSME)

2.2.2 Vapi

Vapi is the second largest city in southern Gujarat, situated in Valsad District, along the bank of River Daman Ganga. The city has an area of 22 km^2 and is located between latitude 20.385° north and longitude 72.91° east. Vapi has an elevation of 27 meters above sea level. Vapi is surrounded by the Union Territories

(UTs) of Daman & Diu and Dadra & Nagar Haveli. The UT of Daman & Diu is divided into two parts by Daman Ganga River – 'Moti' Daman (Big Daman) and 'Nani' Daman (Small Daman). Another river called Kolak flows through both, Vapi and Daman. Just like Surat, Vapi also experiences a tropical climate with heavy rainfall during the monsoon season, with average rainfall being about 90 inches (2279 mm). This city falls under the jurisdiction of Vapi Municipality. The last recorded census of 2011 stated that Vapi has a population of 163,630, with a density of 7292 people per km^2. Vapi is one of the most industrialized towns in the state of Gujarat, courtesy the establishment of Gujarat Industrial Development Corporation (GIDC) Industrial Estate in the city. The industrial sector of Vapi is majorly dominated by chemical and paper industries. Vapi is also home to one of Asia's largest Common Effluent Treatment Plant (CETP), which is administered by Vapi Municipality.

There are 10,716 units of small and medium enterprises (SMEs) operating in the city in different sectors like chemicals, textiles, engineering, and paper industries (Government of Gujarat, n.d.). According to the Central Pollution Control Board (CPCB) of the Government of India, the Daman Ganga river is one of the pollution hotspots in the country. The Gujarat Pollution Control Board (GPCB), Government of Gujarat, advised the company to shift the discharge location from the present upstream location to offshore (Source: Govt appraisal report 2015). Vapi catchment details are tabularized in Table 2.2 below.

Table 2.2: *Vapi catchment details*

Details	Vapi catchment
Name of river flowing	Daman Ganga
Length of river system	131.3 km[#,1]
Area of the catchment	22 sq.km[*,2]
Number of basins within the catchment	2 (Daman Ganga basin and Kolak basin)[3]
Number of inhabitants	163,630[*,4]
Number of urban clusters	2
Number of industries	12,000[5,6] (approx.)
Number of WWTPs/CETPs	11 (approx.)

[1] (U.T. Administration of Daman & Diu, 2019); [2] (Valsad District, n.d.); [3] (Central Ground Water Board, 2013); [4] (Census of India, 2011); [5] (MSME, 2013); [6] (MSME Development Institute); # This is the length of the entire river of Daman Ganga; * Information only for Vapi city and not Nani Daman area.

Figure 2.3 depicts the land use map of Vapi agglomeration. For this project, Vapi City and Nani Daman have been considered in the Daman Ganga catchment area. The rationale has been to include the highly industrialized zones of Vapi and Nani Daman owing to their proximity to the coast where Daman Ganga drains into the Arabian Sea. The lower boundary of the catchment is marked by the boundary of the Vapi Municipal Corporation area, whereas the upper boundary is marked by the coast. The catchment also includes a dam, which goes by the name Daman Ganga Dam, commonly called Madhuban Dam.

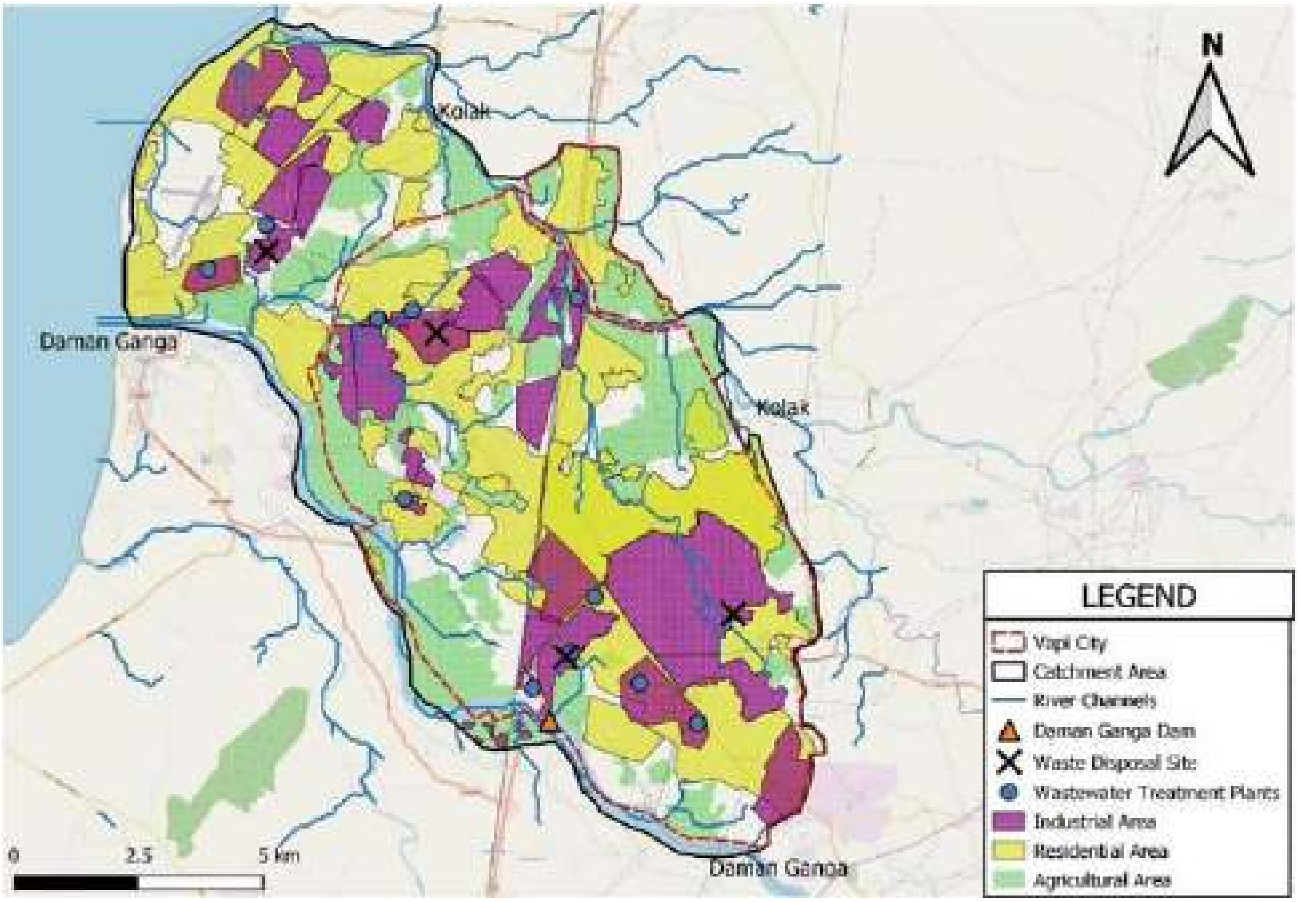

Figure 2.3: Land use map of Vapi agglomeration

Chapter 3
STATUS OF POPs POLLUTION IN THE CATCHMENT AREA OF RIVERS TAPI AND DAMANGANGA

3.1 Introduction to Persistent Organic Pollutants (POPs)

Persistent organic pollutants (POPs) are a group of chemicals that have been intentionally or inadvertently produced and released into the environment. As the POPs are stable and can travel long distances through air currents, they are ubiquitous around the world, including the Arctic, far from where they had been used. POPs have high lipid solubility, and tend to bio-accumulate in fatty tissues of living organisms, especially at the top of the food chain (Xu et al. 2013). The health impacts of POPs include neurotoxicity, cancer, reproductive problems, immunological and endocrine disruption, and skin rashes. (Schecter 1994). Due to the trans-boundary movement pattern of POPs, it is not just a national but a regional/global issue. The Stockholm Convention (SC) was adopted on May 22, 2001 and entered into force on May 17, 2004 (UNEP 2009). The chemicals targeted by the SC are listed in the annexes of the convention text. There are a total of 30 chemicals listed in Annex A, B and C, and in three categories: pesticides, industrial chemicals, and by-products/unintentional production; the details of all 30 POPs listed in the SC is given in this section. In 2004, 12 chemicals or "Dirty Dozen" were listed in SC that are highly toxic chemicals and are harmful to humans and the environment. They are also known as 'legacy POPs' because the present-day contamination is a 'legacy' of past emissions. Thereafter, 18 new chemicals were added that are also referred to as 'emerging POPs' as were recently regulated by the SC. This made the total of 30 listed POPs to the SC. Currently, five chemicals (out of 30 POPs) are listed in both Annexes A and C. The chemical PFHxS is in pipeline, which is expected to be included in the list in 2021. The SC has set measures for each country on the production, import, export, disposal and use of POPs and has put obligations for them on the same.

3.2. Use, emission and release of POPs into environment (Toxics Link, 2018)

3.2.1 Pesticidal POPs

- α-hexachlorocyclohexane and β-hexachlor-ocyclohexane**:** Hexachlorocyclohexane (HCH) is manufactured by photochemical chlorination of benzene. Although the usage of α-and β-HCH as insecticides was phased out a few years ago, these chemicals have been produced as a by-product of lindane. In 1990, India has banned technical HCH from agricultural use but allows it to be used for the purpose of malaria control. There is no information available about the stockpiles of α- and β-HCH. Currently, India does not have any specific policy for α- and β-HCH but there is limited export of β-HCH from the country.

- **Lindane:** Lindane is used as a broad-spectrum insecticide for seed and soil treatment, foliar applications, etc., and have other veterinary and human applications. The production of lindane has decreased rapidly in recent years, but a few countries still produce it. Lindane is no longer produced in India as it is banned from manufacture, import or formulation since 2011 and banned from agricultural use since 2013 but allowed to be used for ectoparasites control under the supervision of the authorities. The food safety and standards for Lindane have specific tolerance limits. There is no stockpiles information on Lindane in India.
- **Chlordecone:** Chlordecone is a synthetic organic compound chemically related to Mirex, an agricultural pesticide listed in Annexure A of the SC. It was first produced in 1951 and commercially introduced in 1958. Currently, no use or production of the chemical is reported, as many countries have already banned its sale and use.
- **Pentachlorophenol (PCP) and its salts and esters:** It has been used as herbicide, insecticide, fungicide, algaecide, disinfectant, etc. High toxicity and slow biodegradation have led to a significant decline in the usage of PCP. The major contaminants include other polychlorinated phenols, polychlorinated dibenzo-p-dioxins, and polychlorinated dibenzo furans. India is one of the leading producers and exporters of PCP but has banned its use from the leather and agriculture sectors. It is widely used as a wood preservative in the country. India exports large amounts but imports negligible amounts of PCP.

3.2.2 Chemicals used in polymers or plastic products

- **Hexachlorobutadiene (HCBD):** HCBD occurs as a by-product during the chlorinolysis of butane derivatives in the production of both carbon tetrachloride and tetrachloroethene. These two commodities are manufactured on such a large scale that enough HCBD can be obtained to meet the industrial demand. There is no information on the release of HCBD in India.
- **Perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride:** PFOS and its closely related members belong to the large family of perfluoroalkyl sulfonate substances (PFASs). They are highly stable (persistent), and are ubiquitous in the environment, wildlife and human blood (Giesy and Kannan 2001; PFOS is produced both intentionally produced (in electric and electronic parts, fire-fighting foam, photo imaging, etc, in several countries) as well as an unintended degradation product of anthropogenic chemicals. There is no specific policy or information on production or stockpiles of PFOS in India.
- **Polychlorinated naphthalenes (PCNs):** They are used as effective insulating coatings for electrical wires, wood preservatives, rubber, and plastic additives, for capacitor dielectrics and in lubricants. It is assumed that the intentional production of PCN has ended, but are unintentionally generated during high-temperature industrial processes. In India, there are no policies or information on use, production, or stockpile of PCNs. However, PCNs are banned in printing ink for food packaging. Although it is not produced in India, there is information on its import/export.
- **Short-chain chlorinated paraffins (SCCPs):** SCCPs can be used as a plasticizer in rubber, paints, adhesives, flame retardants for plastics as well as an extreme pressure lubricant in metal working fluids. The production of SCCPs has decreased globally due to strict regulations. India does not have any specific policy on SCCPs. Also, no information is available on production, stockpiles, export or import of SCCPs in India.

3.2.3 Brominated Flame Retardants

Polybrominated diphenyl ethers (PBDEs) have been widely used as flame retardants in a number of applications. The different commercial PBDE mixtures have been produced and used have been discussed in this section.

- **Decabromodiphenyl ether (Commercial mixture, deca-BDE):** It is used worldwide as an additive flame retardant, that has applications in plastics, polymers, composites, textiles, etc. Deca-BDE containing plastics are used in housings of computers and TVs, wires and cables, pipes, and carpets. There is no information available on production or stockpiles of deca-BDE in India. Although there is no specify policy, the E-Waste (Management) Rules of India (2016), and the EU regulations have certain restrictions on deca-BDE for new electrical and electronic equipment.
- **Tetrabromodiphenyl ether and pentabromodiphenyl ether:** These are the major components of commercial pentabromodiphenyl ether. PBDEs including tetra-, penta-, hexa and hepta-BDEs inhibit or suppress combustion in organic materials and therefore used as additive flame retardants. The production of tetra- and penta-BDEs has ceased in certain regions of the world. (UNEP 2017).
- **Hexabromodiphenyl ether (hexa-BDE) and heptabromodiphenyl ether (hepta-BDE):** These are the major components of commercial octa-BDE. Higher BDEs may be debrominated to lower BDEs, and possibly more toxic, congeners. The higher congeners might therefore be precursors to the tetra-BDE, penta-BDE, hexa-BDE or hepta-BDE. No production of hexa- and hepta-BDEs is reported.
- **Hexabromobiphenyl:** It is an industrial chemical that was used as a flame retardant, mainly in the 1970s. According to the available information, hexabromobiphenyl is no longer produced or used in most countries due to restrictions under national and international regulations.
- **Hexabromocyclododecane (HBCDD):** HBCDD is commercially available in the form of a white solid substance, and has been widely used as a flame-retardant additive on polystyrene materials since the 1980s as a part of safety regulation for articles, vehicles, and buildings.

3.2.4 Mixed usage/Unintentional POPs

- **Pentachlorobenzene (PeCB):** Previously, PeCB was used in PCB products and dyestuff carriers. It was also used as a fungicide and a flame retardant. It might still be used as a chemical intermediate (e.g., to produce quintozene). It is produced unintentionally during combustion, thermal and industrial processes, and present under the form of impurities, in products such as solvents or pesticides.
- **Polychlorinated dibenzo dioxins (PCDD/Fs):** These are unwanted by-products during the combustion of organic materials containing chlorine and of stationary thermal sources like controlled burning of different wastes. The main sources include stationary (thermal processes, chemical industries), diffuse (fuel burning, fires) and secondary sources or reservatories (bio-compost, sewage sludge). Once absorbed, PCDD/Fs will accumulate in lipoproteins in blood, liver, and fat tissues. It is necessary to understand the distribution of these pollutants between different matrices of the environment, and their impacts on human lives.
- **Hexachlorobutadiene (HCBD):** Earlier, HCBD was intentionally produced or used in the production of lubricants, as a solvent, a heat transfer liquid and hydraulic liquid. HCBD is not known to be intentionally produced or used at present, but is unintentionally released from the production of certain chlorinated hydrocarbons, magnesium, etc., and incineration of acetylene, chlorine residues caused by poor abatement control.
- **Hexachlorobenzene (HCB):** It was first introduced in 1945 to treat seeds, and was widely used to control wheat bunt. It is also a byproduct of the manufacture of certain industrial

chemicals and exists as an impurity in several pesticide formulations.

3.3. Research studies on POPs in the environment

Research studies have shown considerable exposure of all organisms as relatively high levels of POPs have been detected in the environment, drinking water, food products and even human breast milk. As per a study conducted by Someya et al. (2010), concentrations of POPs such as PCDDs, PCDFs, PCBs and organochlorine pesticides were measured in human breast milk from lactating mothers residing near an open dumping site and a reference site in the Indian city of Kolkata. Environmental occurrences, source identification, fate and behavior of new POPs in different environmental matrices have been reported in various studies from India. These studies focus on investigating the inter-media transfer/re-mobilization of emerging POPs that are persistent in nature and undergo biomagnification. The study area includes hotspots in Indian cities like open solid waste dumping sites, informal electronic waste recycling stations and riverine/marine ecosystems. Current research initiatives target the identification of cost-effective monitoring techniques and clean-up programs for contaminated sites. The studies by Hashmi et. al. (2019) indicates concentration of POPs in different matrices in Tapi river that has been presented in this section. Such quantitative analysis-based monitoring provides the vital information required by regulators to take appropriate action on these POPs.

3.4 Current scenario of new POPs in India

In the National Implementation Plan (NIP) of India, the MoEF&CC has come out with a new notification on March 5, 2018 that will ban the manufacture, trade, use, import and export of the seven new POPs listed under the SC (Nair 2018). Further on 7 October 2020, The Union Cabinet has approved ratification of these seven POPs. The list of these seven identified POPs is part of the earlier mentioned 16 new chemicals banned by the SC. A brief account of the newly added seven POPs of India, its production, use, and alternatives are elaborated in this section.

3.5 Issue of POPs management and determination of potential data gaps in Gujarat

Out of 30 POPs (intentional and unintentional), India has framed some regulation on the use in certain sectors for 24 POPs. Some of these POPs are partially banned from production. However, study has found the continued use of some these obsolete POPs pesticides in agriculture (Toxics Link, 2018).

3.5.1 Old POPs

The SC seeks an initial twelve chemicals for restriction or elimination of the production and releases. The National Implementation Plan (NIP) of India revealed Palanpur region in Gujarat had a stockpile of 276 Kg of Dieldrin (Technical) and 5100 Ltr of Dieldrin 18% EC (Toxics Link, 2018). The Tapi river was found to be polluted with high levels of endosulfan in surface water, sediment, and fish samples (Hashmi et al., 2019). Pesticides distribution of ΣHCH in air samples from Baroda and Gulf of Kutch were reported (Zhang et al., 2019). DDT and Σ-Endosulfan in both these sites were detected. Average concentrations of ΣHCH/BHC in human blood samples from Ahmedabad was reported in urban areas (Dhananjayan et al., 2010). Similarly, PCBs have been reported from transformers, although PCBs have never been produced in India (Toxics Link, 2018). Another source of PCBs is in the import of ocean liners for shipbreaking. Ship-Breaking Yards, Alang and Sosiya in Gujarat are both PCB contaminated sites (India National Implementation Plan, 2011). The Central Pollution Control Board has monitored PCDD/F levels in ambient air at specific sites and Ankleshwar, Ahmedabad and Vapi have been identified as Critically Polluted Areas in Gujarat.

The major contribution of PCDDs/Fs emission is from waste incineration (67%), ferrous/non-ferrous metal production categories followed by heat and power generation sector. (India National Implementation Plan, 2011). Gujarat being an industrial hub of the country, several industries are the possible sources of PCDDs/Fs in the state. Besides, landfill disposal facilities and sewage treatment facilities are also the site of PCDDs/Fs release. Most of the other POPs like Mirex, Chlordane, heptachlor etc. are either never registered and used in India, or have been banned since long. There is lack of data on the inventories including the current levels of POPs in the environment and the extent of contamination. As a result, there is a constant struggle between stakeholders and authorities over the right course of action for controlling these chemicals.

3.5.2 New POPs

At present, the information on the seven new POPs is limited as India has not created any inventory on these chemicals, and is largely available from secondary sources. Most of these chemicals are industrial chemicals. Industries in Gujarat which are involved in the production of POPs (such as hexabromobiphenyl, hexachlorobutadiene, and decabromodiphenyl ether - decaBDE) have been mapped. As Gujarat is a hub of chemicals, textile, and automobile industries there is a huge possibility of stockpiles of these industrial chemicals. There are companies in Gujarat which are manufacturing polyurethane foams where brominated flame retardants are used. Automobile industries in Vapi and Surat use PFOS, PFHxS and brominated flame retardants as important raw materials during production. PFOS and flame retardants are also used in various households and industrial applications. PCN are unintentionally generated during high-temperature industrial processes in the presence of chlorine. Though intentional use is banned in some of the products, the possibility of unintentional release of PCN cannot be denied. According to Gujarat Pollution Control Board (GPCB), there are 250 organic chemical units, 30 chemical units and 46 textiles units functional under Vapi Industrial Estate (Action Plan for Damanganga River, 2019). This represents possibilities of huge stockpiles of new POPs. Also, waste management is a big issue in Gujarat. In 2018, National Green Tribunal (NGT) ordered all the stakeholders (including GPCB) to act on increasing pollution in Damanganga river and prepare a river action plan. GPCB carries out water quality monitoring at inlet and outlet points of Vapi CETP for the critical parameters. As a result of non-functioning of industries due to the COVID-19 pandemic lockdown (late-March 2020), the CETP was found to comply with most parameters. However, in the post-lockdown period (April-June 2020), the CETP did not meet the inlet norms for COD and NH3-N, and outlet norms for COD and BOD. GPCB had suggested that the CETP needed to follow specific regulations to meet the respective standards (CPCB, 2020).

There is no information on the stockpiles and inventories of these new POPs. Also, there is a lack in research on environmental contamination of POPs and its related human health impacts. There is an urgent need for the identification of cost-effective monitoring techniques, and mapping and clean-up programs for contaminated sites. The analytical methods for new POPs are needed to be developed to provide reliable data for their environmental and biological occurrences, and to investigate their distribution, temporal and spatial trends, environment fates and potential sources. Such quantitative analysis-based monitoring not only helps stakeholders to share responsibilities, but also provides the vital information required by regulators.

Chapter 4
REGULATORY FRAMEWORK, POLICIES AND PROGRAMS IN CHEMICAL WASTE MANAGEMENT (POPs)

4.1 Environmental Governance in India

Article 48A and Article 51A are key provisions of the constitution of India to protect the environment of the country. However, over the years, the judicial interpretation has further strengthened the constitutional mandate and the Supreme Court of India has changed the narrative to guide the development of environmental jurisprudence. And the Apex Court in due course of time has recognized that the 'right to life' guaranteed to the citizens under "Article -21" of the Constitution of India includes 'right to a wholesome environment'. Environmental governance is largely prerogative of the legislature, executive, judiciary with demarcation of power been the central and state government however over the years, civil societies have played a key role in shaping the environmental governance in the country.

4.1.1 Regulations on Chemicals in India

India has several regulations in place to manage the chemicals to minimize the adverse impact of these chemicals on the environment and human health. However, these chemicals are categorized based on the nature of the use of these chemicals like industrial chemicals, and chemicals meant for pesticide use.

The Environmental Protection Act-1986 (EPA) is the umbrella act to look into the protection of the environment in the broader perspectives and there are specific regulations in the EPA to manage the industrial chemicals and Persistent Organic Pollutants (POPs) chemicals. Following rules under the EPA Act are; The Manufacture, Storage, and Import of Hazardous Chemical Rules, 1989; The Chemical Accidents (Emergency Planning, Preparedness, and Response) Rules, 1996; Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016; The Solid Waste Management rules 2016 The Biomedical Waste Management Rules 2016 key to manage the chemicals and waste Further the Insecticide Act-1968 have certain important provisions to manage the pesticides and chemicals.

4.2 India's Program and Policies to Manage the POPs

India ratified the Stockholm Convention on persistent organic pollutants (POPs) on 13th January 2006 and the Convention came into force on 13th April 2006. Subsequently, India came out with the National Implementation Plan (NIP) in 2011 on the twelve designated POPs.

4.2.1 National Implantation Plan of India

The National Plan of India on POPs was released in 2011, five years after the ratification of the Stockholm Convention by the Government of India (NIP, 2011). The National Implementation Plan was prepared after an assessment of the status of 12 initial POPs known as "dirty dozen" to take appropriate action for the elimination of these POPs from the country. The inventory and the assessment of these POPs were carried out by multiple agencies and institutions of the country. Several institutions in the country are involved in the inventory and assessment of POPs. The NIP also identified some key priority areas for the implementation of NIP which can be integrated with the country planning process. Further, to carry out these priority areas, a short-term, medium-term, and long-term action plan was mooted from 2011 to 2020.

4.2.2 Regulation on initial twelve POPs

The National Implementation Plan gave a much-needed overall status of twelve POPs in India. Many of these twelve POPs were pesticides, and the Government of India took initiatives to phase out some of these POPs before the ratification of the Stockholm Convention (SC). To manage the other POPs largely industrial and unintentional POPs, the Government of India started promulgation of new rules and regulations to contain these POPs.

4.2.3 India's position on new POPs

As a party to the SC, the Government of India has been represented at the Conference of Parties (COP) meetings of the SC and negotiated the inclusion of the chemicals as POPs considering its national interest. During the negotiation process, India has raised objections and concerns on the inclusion of some chemicals as POPs including Endosulfan, Pentachlorophenol and its salts and esters, and also sought exemption on the use of chemicals like Deca-bromodiphenyl ether (commercial mixture, c-deca-BDE) etc. for automobile and textile sectors.

The news POPs include pesticides, industrial chemicals, and unintentionally released substances from industrial processes. However, many of these new POPs are brominated flame retardants linked to plastic-based products like electronic industry, automobile industry, toy industry, and textile industry. As India has not updated the NIP, the status of many of these chemicals is not much in the public domain. However, actions have been initiated to restrict the use of some of these chemicals through the Court order, and some regulations have been put in place. The most notable order was the ban on the use, sale, import, and export on Endosulfan by the Hon'ble Supreme Court of India in May 13, 2011. Further the E- waste rules put the restriction on the use of hazardous chemicals like Deca-

Table 4.1: Regulatory actions against different POPs

Types of POPs	Name of the POPs	Regulatory Action
Pesticides	Aldrin, Chlordane, Dieldrin, Endrin heptachlor, HCB, Mirex, Toxaphen	Banned under the Insecticides act 1986 and the rules
Industrial	Hexachlorobenzene (HCB) Polychlorinated biphenyls (PCB)	Order on PCBs by the MOEF&CC in 2016 v
Unintentional	Hexachlorobenzene (HCB) Polychlorinated biphenyls (PCB) Polychlorinated dibenzo-p-dioxins (PCDD) Polychlorinated-dibenzofurans (PCDF)	The Solid Waste Management Rules 2016 The Biomedical Waste Management Rules 2016 The *Hazardous* **and** other *Wastes* (*Management* **and Transboundary Movement**) *Rules, 2016*

BDE etc. Later in March 2018, the Government of India issued a rule known as "Regulation of Persistent Organic Pollutants Rules, 2018", which has put a complete ban on the manufacture, sale and use of the seven POPs which is a very important step considering the linkages of POPs with plastic products. Significantly, on 7 October 2020, the Union Cabinet chaired by Prime Minister Shri Narendra Modi has approved the ratification of seven chemicals listed under the Stockholm Convention on Persistent Organic Pollutants (POPs) (PIB, Govt of India, 7 October 2020). The Cabinet ratification is an important step forward, which will help to fasten the phaseout of these seven POPs chemicals.

4.3 Management of POPs in India

In India, there is a mechanism in place to manage the chemicals from the production to its use and disposal of the waste released during various processes. Several institutions with varied roles (to manage the chemicals including POPs at different levels) are vested with the power to investigate the overall chemical management in the country. Depending upon the nature of the chemicals and its use and release, these institutions have different roles to play to manage the chemicals including POPs at different levels. However, the implementation of these regulations remains a challenge for the country.

The Central Government through the MOEF & CC has derived its power to negotiate the various Conventions including the Stockholm Convention and develop frameworks based on the outcome of the negotiation of the Convention. The national interests were considered by the Government of India while making the rules and regulations on issues related to the global Conventions (such as the SC or Minamata Convention). The Union Ministry of Environment, Forests and Climate Change is the nodal ministry to frame the Rules as well as to coordinate with the Central Pollution Control Board, State Pollution Control Boards as well the Environment Ministries and the Urban Development Ministries of the respective States, to implement the Rules. The National Environmental Engineering Research Institute (NEERI) is the Stockholm Convention Regional Centre (SCRC) for POPs, which is a knowledge resource centre for Asia. However, there is no exclusive authority in India to overview and harmonize the implementation of the Stockholm Convention in the country.

In India, it has been observed that the infrastructure and capacity for POPs management are limited considering the magnitude of the problem. Although there are several laboratories in India with the capacity to measures POPs pesticides, many of these labs have limited capability and protocols in testing the industrial designated POPs.

The local urban bodies have been given the responsibility to manage the POPs. The Government of India issued a regulation, the Solid Waste Management Rules, 2016, in which its bestowed power with the municipalities to manage solid waste. But due to lack of infrastructure, waste is often not managed properly and amongst other problems, it leads to waste burning which is directly linked with the generation of dioxins and furans.

India also has access to the global fund to carry out the innervations on POPs. The development of the National Implementation Plan (NIP) was started in India through Global Environment Facility (GEF) funding. The GEF provided US$ 3,074,700 for the preparation of India's NIP project ("dirty dozen") to meet the incremental costs with a co-financing of US$ 6,880,000 from GOI and US$ 200,000 from UNIDO (United Nations Industrial Development Organization). The project document was signed on 8 November 2007 by the GEF Operational Focal Point in India. The project was very critical to prepare the status report of the first 12 POPs in India and the development of the NIP. Recently India has also received the support of special fund for innervations on chemicals and POPs.

4.4 International Programs on POPs and Chemical management in India

The Stockholm Convention came into force in India on 13 April 2006. India started the development of the National Implementation Plan (NIP) through Global Environment Facility (GEF) funding. A National Steering Committee (NSC) was constituted to guide and monitor the preparation of the NIP. The GEF provided US$ 3,074,700 for the preparation of India's NIP project ("dirty dozen") to meet the incremental costs with a co-financing of US$ 6,880,000 from GOI and US$ 200,000 from UNIDO (United Nations Industrial Development Organization). The project document was signed on 8 November 2007 by the GEF Operational Focal Point in India. The project was very critical to prepare the status report of the first 12 POPs in India and the development of the NIP.

Subsequently, India carried out the projects to eliminate PCBs with the help of UNIDO. India (with the support of UNEP) is developing a roadmap for the substitution of DDT. Further, the Government of India has received a special grant to carry out a project on chemical management including POPs. The project is executed through CSIR- NEERI. Such projects are carried out through a multi-stakeholder approach involving relevant institutions, research bodies, and NGOs. The Government of India has implemented a few projects with the support of the GEF and UNEP special funds to manage the chemicals and POPs.

4.4.1 Environmentally Sound Management and final disposal of PCBs in India

The main objective of this project has been to reduce or eliminate the use and releases of PCBs to the environment through the development and implementation of pilot projects for the environmentally sound management (ESM) of PCBs. It would entail the disposal of approximately 1,700 tons of pure PCBs and 6,000 tons of PCB-contaminated equipment, including PCB-contaminated mineral oils and related waste in three pilot states in India. The project was implemented by GEF, UNIDO, MoEFCC. during November 2009 to October 2013.

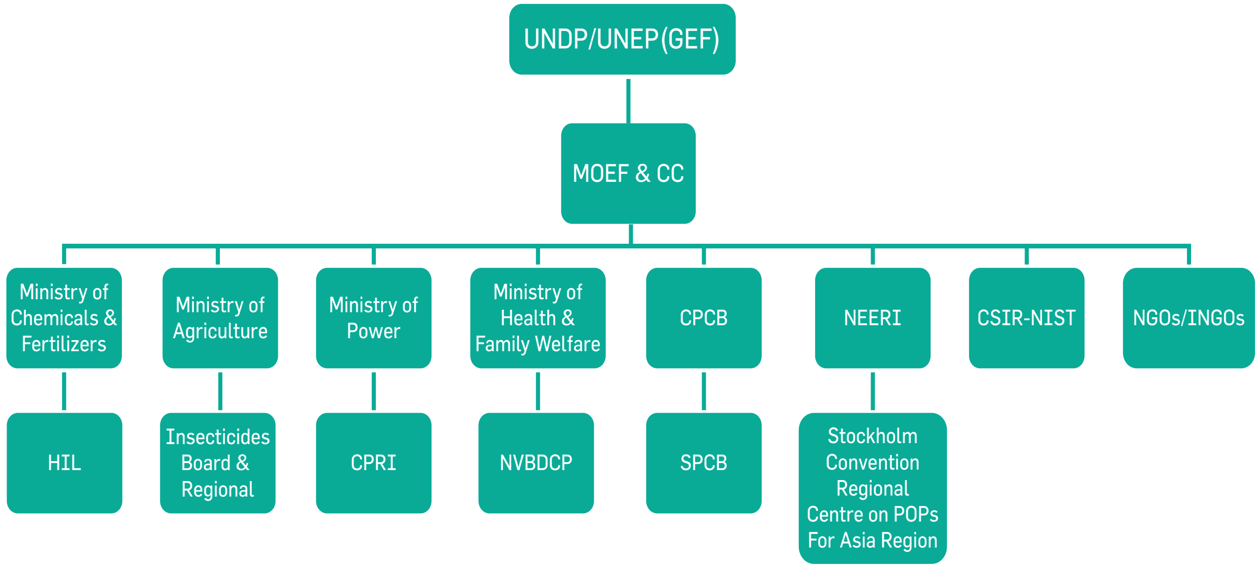

Figure 4.1: Institutional arrangements in India for implementing SC

4.4.2 Environmentally Sound Management of Medical Wastes in India with focal area on POPs

The project was implemented by UNIDO and MoEFCC. The Special Programme Trust Fund amount was USD 550,000 with a total co-financing of USD 350,000. The project commenced in April 2009 with the aim to develop action plans for capacity building on BATs and BEPs; and development of the logical framework and project documents.

4.4.3 Development of a NIP in India as a first step to implement the SC on POPs

The overall objective of this project is to develop the NIP for India to meet its obligation with the Stockholm Convention. Studies on exposure and health impacts of POPs on living systems and of integrated approaches for the replacement of POPs, as well as further capacity building to improve the management of PCBs wastes and the assessment of sources, releases and pathways of unintentional by-products was undertaken during the project. The project was implemented by UNIDO and MoEFCC during September 2007 to August 2009.

4.4.4 Development and promotion of non-POPs alternatives to DDT

The main objective of the project is to introduce bio- and botanical pesticides and other alternatives to DDT as first step for elimination of dependency on DDT, ensuring food safety, enhancing livelihood, and protecting human health and the environment. The project would demonstrate cost-effective, socially acceptable and environmentally sustainable alternatives to DDT and other POPs of similar use. The project was implemented by UNIDO, MoEFCC, MHF&W, MoCF, WHO and other relevant national partners from India.

4.4.5 Institutional capacity building for sustainable management of chemicals and waste with special focus on POPs

The main objective of the project is to strengthen the institutional capacity for the sustainable management of chemicals and wastes (especially POPs) considering the national needs and emerging issues, and work towards better coordination amongst various stakeholders. The project was implemented during December 2018 - March 2022 under the 'developing country' classification by Basel, Rotterdam, Stockholm Conventions.

Chapter 5
POPs ASSOCIATED WITH PLASTIC WASTE

5.1 Routes of exposure (micro, macro, plastic-borne chemicals)

Plastic has been used ubiquitously in households across all socio-economic strata as well as in all geographical landscapes, thereby producing huge quantities of plastic waste which ends up in the natural environment and landfills. It is estimated that plastic comprises 10% of the municipal waste stream [Barnes et al., 2009]. Accounts of plastic pollution range from contamination of soil and agricultural lands by the spread of sewage sludge and irresponsible disposal in surrounding areas [Piehl et al, 2018], accumulation of plastic in waterfalls and riverine tributaries [Mukhopadhyay et al, 2020],

It has been documented that organochlorine pesticides such as dichlorodiphenyl trichloroethane (DDTs), polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) are found on microplastics sampled from the sea. Heavy metals such as aluminum (Al), copper (Cu), silver (Ag), zinc (Zn), lead (Pb), iron (Fe) and manganese (Mn) have also been detected on plastic production pellets sampled in the seawater [Auta et al., 2017]. The extent and proof of chemical pollution via microplastics can be given by the data, which suggests that global concentrations of POPs in marine plastic pellets range between 1–10,000 ng g−1 [Ogata, Takada et al. 2009]. Adsorption of hydrophobic chemicals on plastic substrates leads to the formation of concentrated mass of debris. These aggregates act as a 'sink' for other chemicals, thus providing a protective niche for microorganisms and adsorbed pathogens. Given that STPs release partly treated effluents into sea in the coastal areas, this leads to further accumulation of disease-causing pathogens and micro-organisms. This combination of both microbial and chemical agents onto plastic potentially increases the risk to consumers if fish, crustaceans, or shellfish are contaminated and then consumed [Waring et al., 2018]. Chronic exposure to these chemicals takes place majorly via dietary routes by consumption of foods such as fatty tissues of animals and edible oils.

The available data illustrates interactions between species and materials, and highlights that microplastics represent a multifaceted stressor. Particle-related toxicities are driven by polymer type, size, and shape whereas chemical toxicity is driven by the adsorption-desorption kinetics of additives and pollutants. In addition, microbial colonization, the formation of hetero-aggregates, and the evolutionary adaptations of the biological receptor supplement the increase in complexity of microplastics as stressors [Scherer et al., 2018].

5.2 Environmental, Human and Societal risks associated with plastic pollution

5.2.1 Environmental Risk

Microplastics penetrate aquatic food webs at multiple trophic levels and ecological niches (Figure 5.1). Microplastics, upon ingestion by marine organisms, may cause physical and chemical harm. The consumption of microplastics by marine organisms may cause mechanical effects such as attachment of the polymer to the external surfaces thereby, hindering mobility and clogging of the digestive tract, or chemical effect such as inflammation, decreased growth and hepatic stress. Plastic has been found to host viruses, harmful algal bloom species, and microbial communities, increasingly recognized as the 'Plastisphere'. It is a vector for transport of alien invasive species, and of POPs that may then be ingested in concentrations much higher than the ambient seawater.

Toxic emissions from production process of plastic monomers and incineration of plastic as a disposal mechanism, such as benzene, styrene, formaldehyde and dioxins, furans, mercury, polychlorinated biphenyls respectively, pose a threat to vegetation, human and animal health [Ritchie et al., 2020] [Waring et al., 2018].

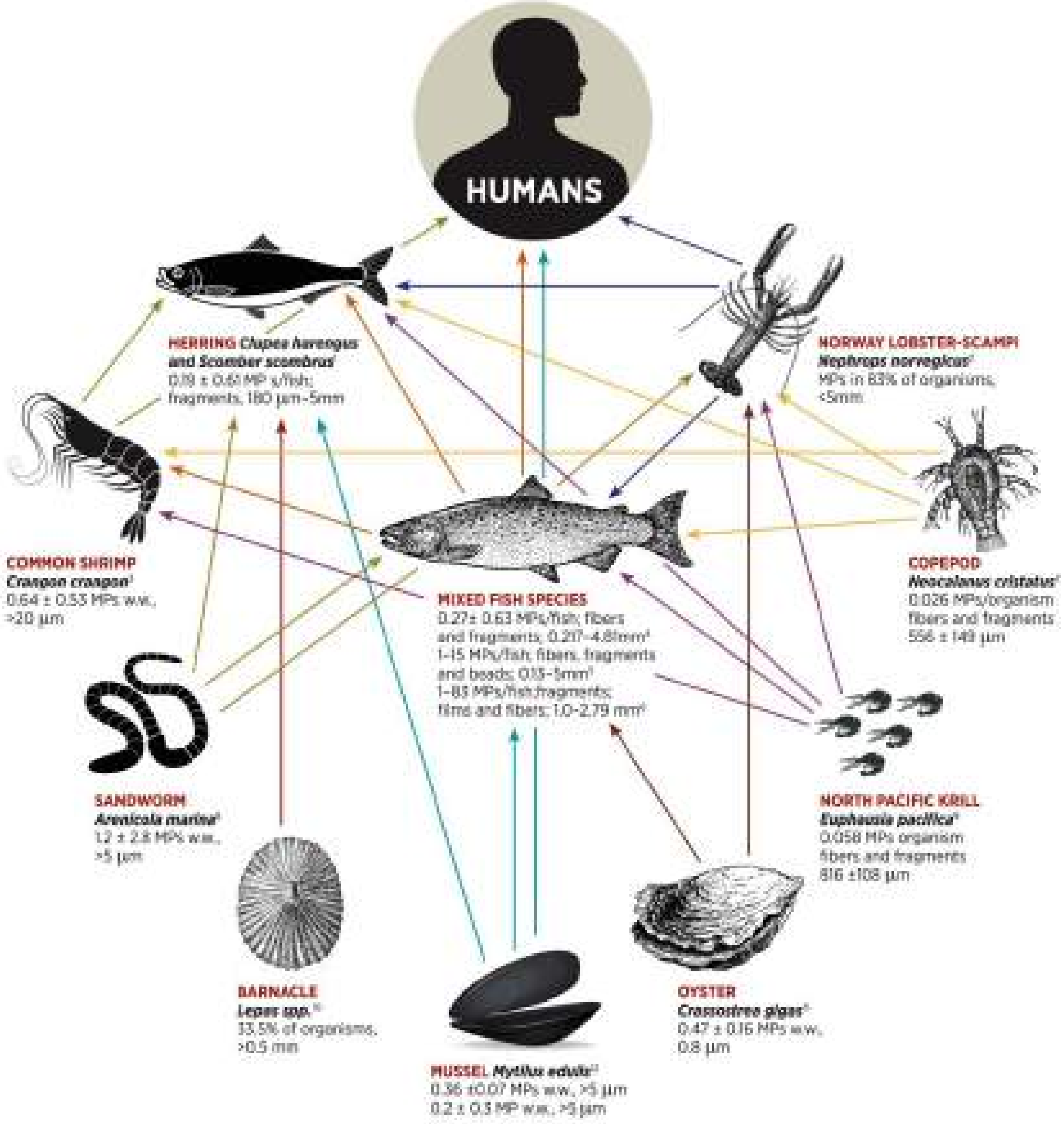

Figure 5.1: Multiple pathways for Human exposure to Microplastic through sea food [*Carbery et al., 2018*]

5.2.2 Human Risk

The chemical nature of plastic associated chemical additives and the documented impact on aquatic animals pose a threat to human life with inconclusive scientific data to demonstrate the cause and effect. Globally, seafood is the primal source of animal protein and makes up about 20% of food intake (by weight) for 1.4 billion people (19% of the global population).

About 37% of the chemicals used in the pre-production process called 'fracking' are suspected endocrine disruptors such as benzene, toluene, ethyl benzene, and xylenes. Polymers once in the environment, can concentrate microbial pathogens and chemicals such as POPs, which can, in turn bio-accumulate in the tissues of marine organisms and eventually bio-magnify in higher organisms including humans. However, consumption of marine plastic by humans will occur on the consumption of a contaminated organism in its entirety, including the gut (e.g., mussels, oysters, sprats, anchovies) [Beaumont et al., 2019] [Horton et al., 2017].

Chemicals released include hazardous monomers such as styrene, vinyl chloride, acrylonitrile, bisphenol A (BPA), and formaldehyde. These chemicals have been labeled as carcinogens or EDCs; their exposure can lead to liver damage, mammary gland tumors, lung cancer, ovarian cysts, endometriosis, and breast cancer, among others. Further additives, including plasticizers, flame retardants, and metals, used in plastic production have similar carcinogenic and endocrine-disrupting health impacts. Diseases resulting from these chemicals are often diagnosed years after exposure and are thus not reflected in industry reports to the government [CIEL, 2019]. The common migrant chemicals from food packaging plastics (like DEHA, BPA, Pthalates, Styrene, and 4-Nonylphenol) and the impacts of these chemicals on human heath has been described in this section.

5.2.3 Societal Risk

Marine workers and tourists are susceptible to injuries due to plastic pollution such as getting entangled in nets, cutting themselves on sharp debris and being exposed to unsanitary items [Beaumont et al., 2019]. Studies also point to consequent economic effects of plastic pollution, such as income loss for fishermen due to plastic debris, loss of tourism revenues and damage to marine industries, which subsequently have social consequences [Kramm et al., 2018].

Plastics are a stressor, which acts conjunctly with other environmental stressors such as those arising from other pollutants, thereby changing ocean temperatures, ocean acidification, and over-exploitation of marine resources. The collective effect of these stressors may result in plastic causing far greater damage in the marine environment than has been documented [Beaumont et al., 2019] [Barnes et al., 2009].

5.3 Inter-linkages between plastics and POPs

Plastic resin pellets found in numerous oceans and seas around the world were found to contain different POPs such as HCHs, DDTs [Ogata, Takada et al. 2009] (Figure 5.2). Electronic and electrical waste recycling in many developing countries like India is another major source for the release of plastic associated POPs such as flame retardants or dioxins [Chakraborty, Zhang, et al., 2017 and Chakraborty, Selvaraj, et al., 2018]. Plastics associated with electrical and electronic items are either discarded or burnt to recover precious metals and in general, mishandled, leading to the emission of POPs from e-waste into the environment [Chakraborty Selvaraj, et al., 2018]. Plastic as a matrix can contain various types of POPs because of any combination of various chemicals; the pathway for exposure to these chemicals associated with plastic waste have been covered in this section.

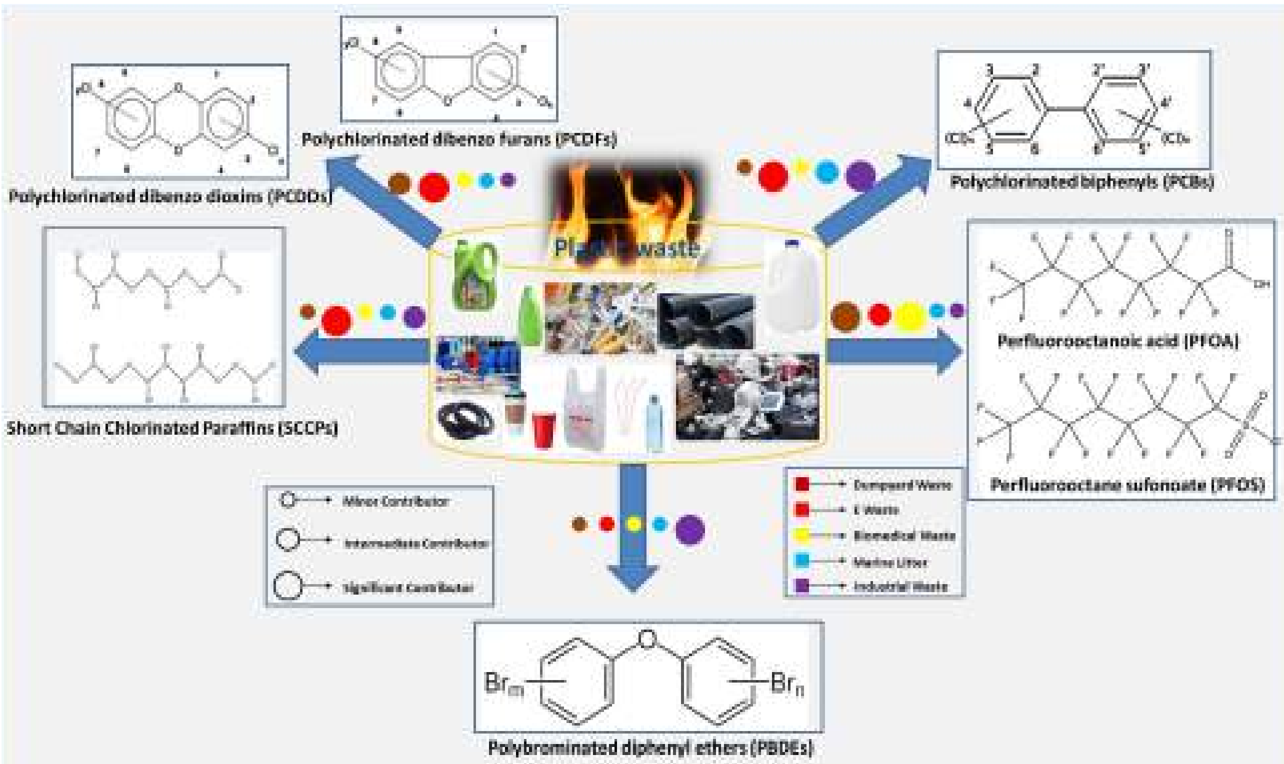

Figure 5.2. Linkage between POPs and plastic waste

Whatever be the origin, plastics do contain POPs and they should be viewed as vectors that may carry POPs to faraway places via long range transport. These tiny particles of plastic are readily mobilized by air as well as water. These are the causes that have led to a growing number of studies that are exploring the link of plastics as a source of POPs pollution in the ocean. Much of the concern around microplastics is associated with their role in introducing persistent organic pollutants (POPs) into marine food webs [Cole, Lindeque et al. 2011]; [Ivar do Sul and Costa 2014].

Given the existing studies on improper disposal and management of plastic waste, POPs arising from plastic as a medium have been condensed under 5 major categories (Dumpyard Waste, E-waste, Biomedical Waste, Marine Litter and Industrial Waste) in the detailed baseline report on pollution due to POPs. This is based on the major sources of plastic waste. This section elaborates the various types of POPs associated with some of their common use in different commercial and industrial products.

5.4 Production of POPs from activities related to Plastic Waste Management

5.4.1 POPs produced due to open burning of plastic waste/ industrial waste/port activities

POPs from dump yard plastics are varied in nature given the vast spread of area from which the wastes are sourced. There is a high likelihood of the plastic picking up or already containing POPs in the form of residues, coating, or splashes before it's journey to the dump. POPs can be released from the plastic, either by means of leachate, gaseous emissions, and sometimes particulate emissions from spontaneous or deliberate waste combustion. Open burning of plastic waste is subsumed as a part of the act of open burning of solid waste. This is mostly observed in developing countries as their waste segregation, recycling and waste processing systems are incapable of handling wastes. Waste burning is a cheap and effective way to achieve volume reduction and is used in dump yards to reduce the height of a pile.

In the case of chlorinated plastics, they give rise to one of the most toxic groups of compounds known to man, PCDD/Fs (polychlorinated dibenzo-p-dioxins and polychlorinated dibenzo-p-furans). So, the possibility of contamination exists in all three environmental matrices leading to catastrophic consequences unless they are curbed. Hence, leachate and gas quality monitoring are mandatorily carried out in a dump yard. However, they are not conducted for POPs and as a result, POPs contamination in a dump yard is not quantified, with no remedy in sight. Significant pollution sources of PCBs are present in the dumping site of Kolkata and the residents living in the vicinity are exposed to relatively higher levels of PCBs [Someya, Ohtake et al. 2009]. Extremely high concentrations of dioxin-like PCBs were detected in fish samples collected from a pond near the dumping site compared to reference site [Someya, Ohtake et al. 2009]. Due to open burning of dumped solid waste, short-chain chlorinated paraffins (SCCPs) in Indian atmosphere are significantly higher than ambient air in Japan, South Korea, and Pakistan, where the concentration of CPs (chlorinated paraffins) are comparable [Chaemfa, Xu et al. 2014].

The most obvious industrial waste stream that contains POPs is the waste from the chemical production of established POPs like pesticides, flame retardants, surfactant chemicals. However, these are not the only sources of POPs from industrial waste. Industries are one of the major users of packaging, insulation, and other value additions to safeguard their product which also contribute to the problem of POPs. Industrial waste can sometimes combine to release POPs in a more effective manner than their individual components [Sakai et al. 1998].

5.4.2 POPs released from plastic handling/recycling activities (dedusting, washing, melting, etc.)

5.4.2.1 POPs in plastic waste from e-gadgets

The informal sector recycles about 95% of e-waste in India [Chakraborty, Selvaraj et al. 2018]. Urban slums and suburbs are the major locations where unorganized recycling is carried out in and around major metropolitan cities of India. The 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, Selvaraj et al. 2018]. Plastic processing, open burning in dumpsites and informal e-waste recycling at specific locations within each metropolitan city of India are suspected to have collectively impacted the atmospheric emission of PBDEs [Chakraborty, Zhang et al. 2017]. A significant correlation was found between DEHP (di(2-ethylhexyl) phthalate) and a previously reported polychlorinated biphenyl (PCB) congener, PCB–126 from the same e-waste shredding and recovery sites where extensive burning of plastic or PVC materials were prevalent [Chakraborty, Sampath et al. 2019].

5.4.2.2 POPs in plastic waste from biomedical waste

Most of the plastics used in a hospital are chlorinated in some form or the other, leading to the possibility of the formation of PCDD/Fs during incineration. PCB congeners were reported to be co-generated with PCDD/Fs in incineration plants in India. Many incinerators have trouble controlling dioxin emissions because of the poor performance of combustion chambers or air pollution control devices (APCDs), discontinuous operation, or irregular waste feeding [Thacker, Sheikh et al. 2013]. Without proper safeguards, biomedical waste processing ends up as an unintentional source for POPs.

5.4.2.3 POPs in plastic waste from marine litter

Microplastics act as vectors of POPs, and aids in the translocation of pollutants from the organism to the plastic particles. They help in reduction in accumulation of contaminants in the tissues of marine organisms, and function as vectors of contaminant reduction in marine biota, as they can alter the bioavailability and the path route of a contaminant. However, microplastics cannot be considered for remediation to environmental contamination of marine biota.

5.5 Human, societal, and environmental risks associated with plastic and chemical interlinkages

This section highlights the various plastic and associated chemicals, their usage, common uses, and related health impacts. Given the ubiquitous nature of plastic, it invariably ends up as waste and when poor waste management system is aided with a complex waste stream, it results in mishandling. Emission of PCDD/Fs as a result of informal e-waste recycling is a case in point. [Chakraborty, Zhang, et al., 2017]. POPs and other chemicals released along with plastics pose a threat to the environment and human health. Open burning of dumped waste, untreated wastewater and storm-water are reported to be the main sources of both BPA and PAEs in riverine sediments [Mukhopadhyay et al., 2020]. Effluent outfall from STPs, untreated wastewater discharge from industries and domestic sources were related to higher percentage of nonsteroidal anti-inflammatory drugs/preservatives in urban areas [Chakraborty, Selvaraj et al., 2018]. The sheer number of additives (to plastic) and the lack of a universal production process makes it difficult to assess the chemical makeup of a plastic, thereby leaving us exposed to more harmful and unknown compounds.

Chapter 6

SUMMARY POPS HOTSPOTS IN RIVER TAPI (SURAT) AND DAMAN GANGA (VAPI)

6.1 Background

The “Golden Corridor” of the Indian State of Gujarat is an industrial belt that runs along the main north-south highway, linking the southern town of Vapi, with northern state capital of Ahmedabad. Major industrial areas include the large industrial estates of Ankleshwar, Nandesari and Vapi. These industrial areas contain thousands of individual industrial units, including dye factories, textile, rubber, pesticide and paint manufacturers, pulp and paper producers, pharmaceuticals, engineering, and chemical companies (CPCB 1996,). Piles of sludge and solid waste are dumped indiscriminately on open ground, and roadside ditches that carry the mixed effluent to pumping stations, rivers and waste treatment facilities such as Common Effluent Treatment Plants (CETPs), where the effluent is treated to secondary stage.

As per the report published by Gujarat Ecological Commission (GEC), 2004 on the status of coastal pollution in Gujarat due to industrial and human activities, CETP for the industrial units were reported to be an emerging threat. CETPs cannot treat certain types of pollutants like heavy metals, mercury, and POPs. The disposal of hazardous waste and technical capability to measure emission levels need urgent attention. The coastal waters of Gujarat are expected to receive 606 Mm^3 domestic sewage and 215 Mm^3 industrial effluents every year. In addition, about 14000 tons of domestic solid wastes are dumped into the sea. Coastal industries generate five million tons of solid wastes. At present, there are no estimatesfor agricultural runoff into the sea with increasing levels of pesticides and fertilizers from the districts of Kutch, Kheda, Surat and Valsad that are likely to contribute excess nutrient. In 2007, the total hazardous waste generated in Gujarat amounted to 1.767 Million Metric Ton/Annum. Out of which 64% of waste was landfillable, 30% was recyclable and meager 6% was incinerable. The districts located in the golden corridor (Ahmedabad to Valsad) with the highest industrial activities had much higher waste generation than other districts (Hazardous Waste Inventory as on 31.08.2007, GPCB).

The status of POP pesticides wastes identified through preliminary investigation of the areas of POPs as per National Implementation Plan of India revealed Palanpur region in Gujarat reporting stock pile of 276 Kg of Dieldrin (Technical) and 5100 Ltr of Dieldrin 18% EC (Emulsifiable Concentrate). The production and distribution of ΣHCH in air samples in Baroda and Gulf of Kutch reported by Zhang et al. (2008) were 2275 and 131pg/m^3, and DDT and α-Endosulfan in both these sites were 566 &112pg/m^3 and 317&12 pg/m^3 respectively.

6.2 POPs concentrations in environmental matrices of Gujarat

Various research studies show the concentrations of POPs in different matrices collected from Ahmedabad and different parts of Gujarat as presented in **Table 6.1**. Additionally, CPCB has monitored Dioxin (PCDDs) / Furan (PCDFs) levels in ambient air and Critically Polluted Areas (CPAs) in Gujarat, such as: Ankleshwar, Ahmedabad and Vapi. The ship breaking yards located at Alang and Sosiya in Gujarat are considered as probable PCB contaminated sites. The shipbreaking yards in Alang-Sosiya of Gujarat stretch on a 10 km long beach with a vast tidal range. Alang-Sosiya is the world's largest shipbreaking site (NGO Shipbreaking Platform. N.d.). In Baroda and Gulf of Kutch, the mean atmospheric concentration in pg/m^3 have been reported in 2008 viz., ΣPCBs (688,320), α-HCH (300,31), γ-HCH (1975, 100), HCB(133,45), *o,p′*-DDT(135,77), *p,p′*DDT (39, 21), *p,p′*-DDE(395, 14), ENDO-I(317, 12), ΣPBDEs(14, 2) (Zhang et al., 2008).

6.3 Tapi riverine environment

There are studies on the presence of POPs in Tapi river. Pesticide residues in water, sediments and fish samples from Tapi River were analyzed by Hashmi et al 2020 and endosulfan, chlorpyrifos, and methyl

Table 6.1: Concentration of POPs in different matrices in Gujarat

Sl No	District	Matrix	Chemicals	Concentration	Reference
1.	Ahmedabad	Human blood samples	ΣHCH/BHC	41.2 (g/l)	Bhatnagar et al. (2004)
2.	Ahmedabad	Human blood samples	ΣHCH/BHC	148 (g/l)	Bhatnagar et al. (1992)
3.	Ahmedabad	Human blood samples	ΣDDT	32.6 (g/l)	Bhatnagar et al. (2004)
4.	Ahmedabad	Human blood samples	ΣDDT	47.7 (g/l)	Bhatnagar et al. (1992)
5.	Ahmedabad	Human milk samples	ΣHCH/BHC	224.6 (ng/g lipid wt.)	Jani et al. (1988)
6.	Ahmedabad	Human milk samples	ΣDDT	305.83(ng/g lipid wt.).	Jani et al. (1988)
7.	Ahmedabad	Human Brain,	ΣHCH	1.9–893 (mean-128) (ng/g),	V. Dhananjayan and S. Muralidharan, 2013
8.	Ahmedabad	Human liver	ΣHCH	3.6–3054(mean- 565) (ng/g)	V. Dhananjayan and S. Muralidharan, 2013
9.	Ahmedabad	Human muscle	ΣHCH	3.9–1991(220) (ng/g)	V. Dhananjayan and S. Muralidharan, 2013
10.	Ahmedabad	Human Brain,	ΣDDT	Between ND–117 (mean- 20.3) (ng/g),	V. Dhananjayan and S. Muralidharan, 2013
11.	Ahmedabad	Human liver	ΣDDT	4.3–1079 (mean- 248) (ng/g)	V. Dhananjayan and S. Muralidharan, 2013
12.	Ahmedabad	Human muscle	ΣDDT	non-detected–1031 (184) (ng/g)	V. Dhananjayan and S. Muralidharan, 2013
13.	Ahmedabad	Human Brain,	ΣPCBs	Between 30–1346 (mean- 359) (ng/g),	V. Dhananjayan and S. Muralidharan, 2013

Sl No	District	Matrix	Chemicals	Concentration	Reference
14.	Ahmedabad	Human liver	ΣPCBs	40–5790 (mean- 825) (ng/g)	V. Dhananjayan and S. Muralidharan, 2013
15.	Ahmedabad	Human muscle	ΣPCBs	46.8–4063 (220 646) (ng/g)	V. Dhananjayan and S. Muralidharan, 2013

parathion were observed in surface water with concentrations of 37.56 mg/L, 0.86 mg/L and 0.43 mg/L, respectively. Endosulfan, DDT and methyl parathion detected in sediment were 38.38 ng/g, 0.65 ng/g and 0.77 ng/g, respectively. In fish samples, levels of endosulfan, chlorpyrifos, and methyl parathion detected were 101.28, 0.392, and 3.49 ng/g correspondingly. Concentration of DDTs and HCHs residues detected in the river sediment samples were in the range 0.52–0.72 (mean- 0.65) ng/g and ND (Hashmi et al., 2020).

6.4 Daman Ganga riverine environment

The Vapi industrial estate is made up of nearly 2000 industrial units producing wide range of chemicals, pharmaceuticals, dyes, pesticides and other agrochemicals, and plastics (PCB 1996), with dye manufacturers and dye intermediate units contributing to the largest quantity of hazardous waste (CPCB 1996). Effluents from the CETP in Vapi Industrial estate are discharged into the Daman Ganga River. A total of three samples were taken from the Vapi industrial estate, including two water samples, and one sediment sample **(Figure 6.1)**. Operational CETP receives a complex mixture of wastes from many different sources and treated wastewater is discharged into the Daman Ganga River, close to the CETP. The treated and untreated wastewater samples were found to be heavily contaminated by organochlorine compounds.

A total of 18 and 35 organic compounds were isolated from treated and untreated water samples respectively. 12 organic compounds (67%) and 22 organic compounds (63%) were reliably identified in

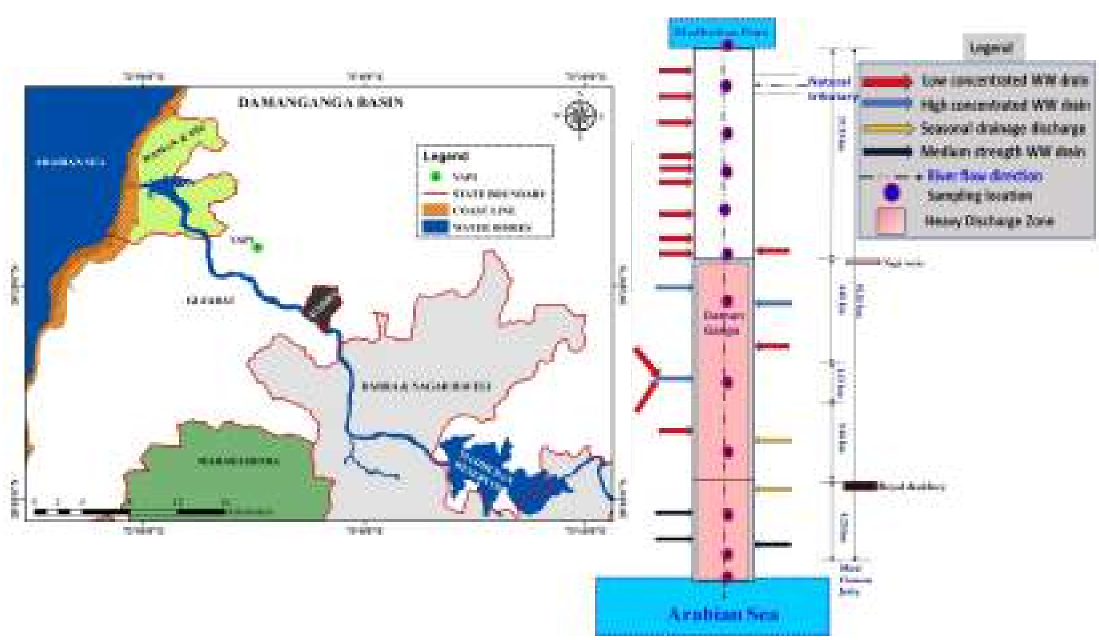

Figure 6.1. Discharge of Industrial Effluents in Daman Ganga river

these samples. Organochlorine compounds represented the majority of reliably identified compounds in both samples; 10 and 11 of those were found in both the samples. The classes of detected organic compounds were: di-, tri-, tetrachlorobenzenes and chlorinated benzenamines, diphenyl ether. Additionally, untreated sample contained chlorinated a pyridine derivative and naphthalene. Treated sample contained penta- and hexachlorobenzene, dibenzothiophene derivative and linear aliphatic hydrocarbons.

Seventeen organohalogen compounds were reliably identified in the sediment sample including di-, tri-, tetra-, penta- and hexachlorobenzenes, chlorinated benzenamines, chlorinated diazo benzenes and PCBs. Other organic compounds found in this sample included cresols, a phthalate ester (DEHP), benzaldehyde, a benzothiazole derivative, N-alkylated benzenamines, a carbazole derivative, the pesticide chlorpyrifos and linear aliphatic hydrocarbons (Labunska.,1999). Central Pollution Control Board has, to some extent, monitored Dioxin (PCDDs) / Furan (PCDFs) levels in Ankleshwar and Vapi region. Volatile Organic Compounds (VOCs) were monitoring and assessed in ground water and surface water samples collected from sampling locations from selected Critically Polluted Areas (CPAs) of Ankleshwar and Vapi in Gujarat and 43 Volatile Organic Compounds (VOCs) were identified by National Reference Trace Organics Laboratory, CPCB (NRTOL, CPCB, n,d.).

6.5 New POPs in Tapi and Daman Ganga

Recently, the Government of India has notified addition of 7 new compounds to the list of POPs in the “Regulation of Persistent Organic Pollutants Rules, 2018”. There is a wide gap in data on the inventories and the current levels of these compounds in the environment and the extent of contamination for many of these notified compounds are unknown. This report aims to act as a repository/ready reckoner for information related to HCHs, PBDEs, PCDD/Fs & SCCPs, and their current scenario at either the national or global level. Technical information related to analysis and sampling are also provided for selecting an approach that is most appropriate for the undertaking at hand and the compounds involved.

Chapter 7
TRANSPORT OF POPS FROM SOURCE TO SEA

7.1 Persistent Organic Pollutants under the Stockholm Convention

Under the 2001 UNEP Stockholm Convention (SC) on Persistent Organic Pollutants (POPs), signatory countries are legally required to eliminate or restrict production, use, and emissions of several substances with elevated environmental persistence, potential for undergoing long-range transport from source points and bioaccumulation capacity. The goal of the SC is to reduce human and ecosystem exposure to these hazardous contaminants.

Chemical management towards the implementation of the SC has internationally focused on inventorying and eliminating/limiting primary sources of regulated substances. Successful reduction of primary sources has been reflected in monitoring results that indicate globally declining atmospheric levels for some POPs (especially polychlorinated biphenyls (PCBs), hexachlorobenzene (HCB), and dichloro-diphenyl trichloroethanes (DDTs)) that are steadily declining in Europe, North America, and the Arctic (Brun et al., 2008;). However, there are still ongoing primary releases from diffuse sources that are difficult to target for reduction or elimination, such as volatilization from old stockpiles, or from old equipment.

Furthermore, new groups of substances are added to the SC over time. Between 2009 and 2019 several industrial substances such as a range of polybrominated diphenyl ethers (PBDEs) flame retardants, some perfluoroalkyl substance (such as PFOA and PFOS) used as coating agents and surfactant in several industrial applications, several polychlorinated naphthalenes and paraffins (used as insulation and thermal control oils) and some new organochlorine pesticides, have been added to the SC list.

Implementation of SC at a global scale presents challenges linked to lack of harmonization of processes and capacity in different countries. Hence, inventorying and curbing of primary sources of POPs is an actual ongoing challenge far from being completed. Part of the challenge of identifying source hotspots is also linked to the complex behaviour these substances have in the environment.

7.2 Environmental cycling of POPs and exposure of ocean environments

Because of their physical and chemical properties, POPs have complex behaviour in the environment. Environmental compartments such as soils, vegetation, water bodies, and sediments that were contaminated in the past act as environmental capacitors and potentially secondary sources to transport compartments (e.g. water and air) (Nizzetto et al., 2010). The environmental cycling of POPs, and consequently their environmental concentrations are the result of a complex interplay of processes that controls the intercompartment exchanges (e.g. diffusion between soil or water and air) and the co-transport with solids (e.g. contaminated particles in air and water). A substantial fraction of the regulated POPs ever produced is believed to be currently stored and circulating in the environment (Nizzetto et al., 2010). Understanding the biogeochemical controls on the environmental fate of POPs is key to elucidate, quantify and predict the transport of POPs from primary sources to terrestrial and marine environments.

Measuring POPs in the environment is costly and difficult. Mathematical multimedia fate models can therefore be useful to estimate complex transport processes, loosely constrained with a paucity of available empirical observations.

Important sources of POPs to the ocean includes areal transport, deposition of atmospheric organic particles, and gaseous exchange between air and surface water. Although the atmospheric loads represent a relatively small fraction of the total burden of most POPs, the global extension of ocean surface and the efficiency of atmospheric transports makes the gaseous exchange between the air/water interface a crucial process for the global fate of POPs and for the exposure of the marine environment (Lohmann et al., 2007).

Riverine transport is believed to represent a key source of POPs for coastal environments. While regulatory monitoring programs in many countries focus on monitoring concentration of several POPs in rivers to the scope of protecting freshwater and coastal environments (see for example the European Water Framework Directive), the overall significance of riverine transport as a source of ocean pollution is still poorly understood.

7.3 Sources and transport of POPs in rivers and discharges to the ocean

Rivers are highly dynamic ecosystems that respond directly to both climatic and anthropogenic drivers. POPs entering the riverine system interact with water, water constituents (e.g. organic matter) and sediments. Understanding, quantifying and predicting the cycle and transport of POPs in rivers requires therefore disentangling these complex interactions and resolving the problem of describing a highly dynamic and changing system.

The key sources and processes controlling the fate and transport of POPs in rivers are illustrated in **Figure 7.1**. POPs can be released from primary sources in urban, industrial and agricultural landscapes (especially in the case of pesticidal POPs) to the atmosphere. In the atmosphere they are rapidly distributed in the environment at regional, continental and global scale.

POPs can then be deposited with atmospheric depositions (rain, snow or particle deposition) over land and ocean surfaces. Following deposition, POPs are stored in vegetation and soils where they can persist over decades. In the case of agricultural landscapes, pesticidal POPs are directly added to soil. Rain and erosion of soils drive the runoff of POPs toward the water environment from both natural and agricultural soils (Sanka et al., 2018) DDT remains ubiquitous in soils due to its persistence and intense past usage. Because of this it is still a pollutant of high global concern.

POPs can also be primarily discharged to water from source points, especially in urban and industrial areas (Li et al., 2016). This is the case particularly of perfluoroalkyl substances (PFAS) that have high solubility and are generally discharged directly to water from municipal and industrial wastewater (Sharma et al., 2016). River sediments can serve as an important storage of these contaminants, which significantly delay their transport towards the ocean (Nizzetto et al., 2016).

7.4 Environmental fate models for riverine transport

Rivers are described and observed as important net sources of POPs to the marine coastal environment

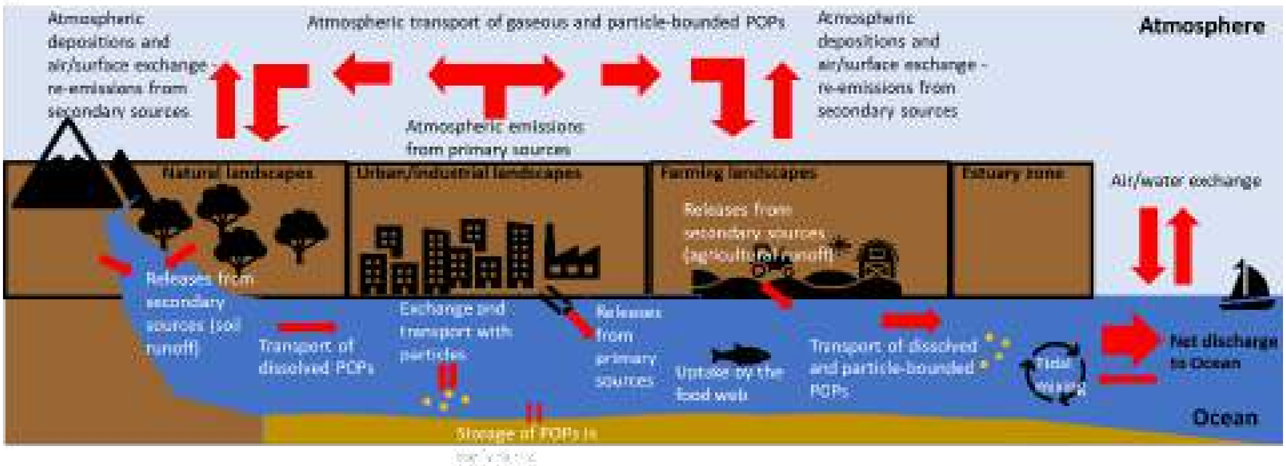

Figure 7.1. Sources and processes controlling fate and transport of POPs in a catchment and river system, and their discharge to the Ocean

(Lin et al., 2016, Nizzetto et al., 2016). Quantitative assessments of this role is however still fragmentary, as measuring and monitoring POP discharge by rivers is a complex and costly operation. Environmental fate models are useful tools to overcome these limitations. Models capable of describing both the complex biogeochemical drivers and multimedia exchange in highly dynamic systems are vital for understanding POP transport and sources to marine coastal water in different rivers and under different conditions.

Developing tools for understanding and predicting the behaviour of chemical contaminants with multiple emission pathways and complex environmental behaviour is an essential step for prioritizing and implementing effective pollution management strategies.

Several mathematical models have been developed to facilitate exposure assessment of chemical contaminants, particularly within the fields of multimedia fate models (MMFMs) and water quality modelling (WQMs). MMFMs typically adopts a simplified representation of the connection between biochemical processes and contaminant fate and transport, while WQM-derived contamination models tend to include very detailed dynamic descriptions of the aquatic environment.

There are trade-offs between the use of either MMFMs or WQMs and the unbridged gap between these two approaches can severely limit the ability to assess details of contaminant environmental fate. Fortunately, new integrative modelling tools are becoming available to predict fate and distribution of multiple contaminants in realistic river environments (Nizzetto et al., 2016; Sanka et al., 2018), however they require a high level of detail in of certain parameters.

7.5 Fate of Organic Pollutants in the Sea

The fate of organic contaminants in marine waters largely depends on the structure and physico-chemical properties of the substances, the emission pathway and the recipient's environment (physical, chemical and biological conditions). **Figure 7.2** (Brumovský, 2017) shows the schematics of the processes controlling the fate of organic pollutants in the marine environment.

Contaminants can be present in the water column dissolved or adsorbed onto suspended particles and colloids. Volatile and semi-volatile compounds are subject to air-water exchange. Whether dissolution into the water phase or volatilization takes place is determined by the contaminant's fugacity in both environmental compartments. During sinking, a major fraction of the organic matter is consumed by bacteria. This process results in net loss of capacity of fugacity of the sinking materials and may lead to the desorption of bound persistent substances that will be degraded at a slower rate compared to the natural organic matter. Such an uncoupling of contaminant fate and organic matter fate has not been studied in detail and knowledge on the role of marine bacterial loop on contaminant fate is scarce (Sobek et al., 2004). In areas of strong water currents, upwelling, or shallow waters, sediments can be resuspended and mobilized in the water column. Therefore, coastal sediments are not final sink of POPs (Jönsson et al., 2003). In case of banned substances (POPs) the historical pollutant burden accumulated in the sediment can constitute a major environmental reservoir and a possible important secondary source for the water column (García-Flor et al., 2009).

7.6 Uptake of POPs by marine biota

Organisms living in the marine environment are exposed to contaminants present in seawater and sediments. It is believed that the dissolved concentration represents the relevant exposure indicator since dissolved species are bioavailable and may be transferred into organisms (i.e., via passive diffusion through the cell membranes). Research shows that hydrophobic contaminants, such as many POPs, accumulate in fat tissues, while other contaminants, such as certain

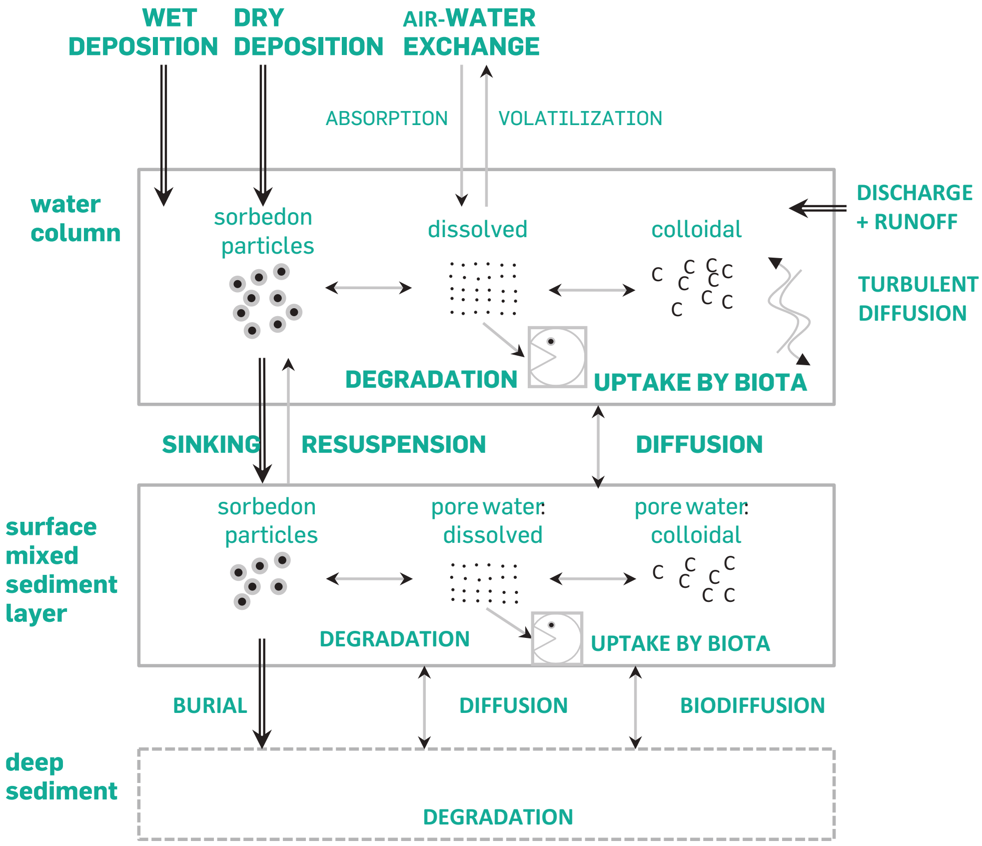

Figure 7.2 Processes driving the environmental fate of organic pollutants in marine waters (adapted from (Jurado et al., 2007)) and uptake by marine biota. Marine organisms can uptake contaminants dissolved in water, through diffusive process across the body surfaces or through the diet.

PFASs, strongly binds to proteins. Heterotrophic organisms accumulate POPs primarily from the diet through a process known as biomagnification. Some contaminants pass in fact along the food chain and can be accumulated at exponentially increasing concentrations in the higher trophic levels. Intake of contaminated food can be a major source of contaminants for animals (and humans) at the top of predatory chain, e.g., seabirds and marine mammals (Gray, 2002).

7.7 Transformation processes in the sea

Transformation processes acting on marine contaminants can be divided between biotic and abiotic. Abiotic processes include chemical reactions, such as hydrolysis and redox reactions, as well as photochemical processes taking place in the photic zone of oceans. Biotic processes are mediated by living organisms (including both microorganisms and metabolism of higher organisms) and may be further divided between oxic (i.e., with the presence of oxygen) and anoxic (i.e., without oxygen). Transformation under oxic conditions are generally favoured because many organic contaminants are susceptible to oxidation. Anoxic degradation is possible in sediments where contaminants are deemed persistent in the oxic environment, but varying environmental conditions (e.g., temperature, intensity of sunlight, soil composition and viability and humidity) may significantly influence chemical's removal rates.

7.8 Long range transport of marine pollutants

Oceans are crucial players for the global cycling of POPs. Ocean currents are important vectors for the long-range transport of certain environmental pollutants. Pollutants can be divided in swimmers, flyers, and single/multiple hoppers, according to their partitioning behaviour among environmental compartments that drives the mechanisms of environmental transport. Swimmers are the chemicals that have high solubility in water and low volatility. These are usually ionic or very polar compounds such as pharmaceuticals, some herbicides, perfluoroalkyl acids/sulfonates and others. Once they have entered a water body, these chemicals follow the movement of water until they are degraded or absorbed to sediment or sinking particles. The flyers are chemicals with high vapour pressures and tend to be volatilized and remain in the atmosphere until they are degraded, for example by reaction with OH radicals. Therefore, oceans do not play a major role in the environmental transport of those substances. The hoppers are a large group of chemicals which include most POPs, they are semi-volatile and have relatively low water solubility and high affinity for organic matter. These chemicals, depending on their persistence and properties, can undergo successive steps of volatilization/deposition and thus affect all environments and ecosystems regardless of their source in the environment (Jurado and Dachs, 2008).

Chapter 8
ENVIRONMENTAL MONITORING TECHNIQUES OF TARGETED POPs

8.1 Sampling techniques

8.1.1 Air (Gaseous/Particulate)

Active air sampling involves pumping of air into a solid polymeric adsorbent material, to which airborne POPs get absorbed. The sampling rate needs to be determined beforehand so as not to impair capture of the compound onto the surface of the adsorbate. Particulate matter is collected simultaneously by adding a filter paper of appropriate size before the adsorbate, during sampling. Passive air samplers (PAS) absorb POPs from the air onto a sorbent by physical processes, such as diffusion. Polyurethane foam disk passive air samplers (PUF-PAS) have been extensively used in India for monitoring organochlorine pesticides (OCPs) (Chakraborty et al., 2010), polychlorinated biphenyls (PCBs) (Pozo et al., 2009) and polybrominated diphenyl ethers (PBDEs) (Chakraborty et al., 2017). Chakraborty et al. (2010) has standardized such time integrated PUF-PAS against an active sampler for organochlorine compounds.

Figure 8.1: Typical high-volume air sampler

8.1.2 Water (Surface water/ Groundwater)

Grab and composite sampling are the most common sampling techniques for surface water samples. A grab sample is an individual sample collected randomly at a specific time from any location.

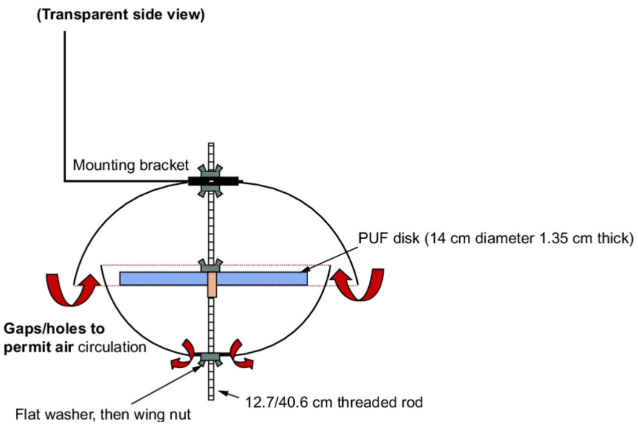

Figure 8.2: Schematic of a typical passive air sampler

Figure 8.3: Sediment corer for core sampling

Figure 8.4: Soil scoop for sampling

Figure 8.5: Grab sampler for sediment collection

A composite sample is a representative sample prepared from a combination of multiple grab samples collected at definite time intervals or locations. In the last few decades, passive samplers are also gaining popularity for water sampling. The technique primarily measures the concentrations of freely dissolved compounds during an integrated period of time (Lohmann et al., 2017).

8.1.3 Soil/Sediment

Surface soil is usually sampled by a spade or a scoop. Subsurface soil is commonly collected by tube/core samplers. Generally, a grab sampler is used only if the surface riverine sediment is needed, and a core sampler is used to collect historically deposited sediments or deep sediments (Figure 8.3, Figure 8.4, Figure 8.5).

8.1.4 Biota

Different biota samples such as human breast milk, blood, fish, food/edible products are often collected to monitor exposure of living organisms to POPs. Special care is taken not to contaminate the samples with external sources. As most of these compounds are lipophilic, the lipid content in the matrix should be considered and it would often be preferable to determine the lipid content in the sample for comparison with other results and studies.

8.2 Extraction techniques

Solid samples (Soil/Sediment/Dust/Biota)

Samples contaminated with POPs, such as soil, sediment, sewage sludge and biotic samples, adsorbent materials from gas sampling such as quartz-fiber filter and a PUF adsorbent, need to be subjected to extraction. Generally, the extraction of solid samples is carried out by the conventional or well-established techniques, such as liquid-solid extraction, sometimes combined with microwave-assisted extraction (MAE) or ultrasound assisted extraction (UAE).

Extraction methods from liquid samples (Water)

The extraction of liquid samples or clean-up and fractionation of raw extracts from the solid samples involve solid phase extraction (SPE) using online or offline approaches. SPE technique uses a stationary phase/resin in an extraction cartridge or disc to extract non-polar analytes from polar liquids (Figure 8.6).

The elution of the cartridge or disk can be done in several steps to separate several classes of compounds or in one step for many analytes, which can significantly reduce solvent usage and analytical time. The cleanup of the sample extracts can generally be carried out in a glass column involving combinations of different adsorbents such as silica, alumina, etc.

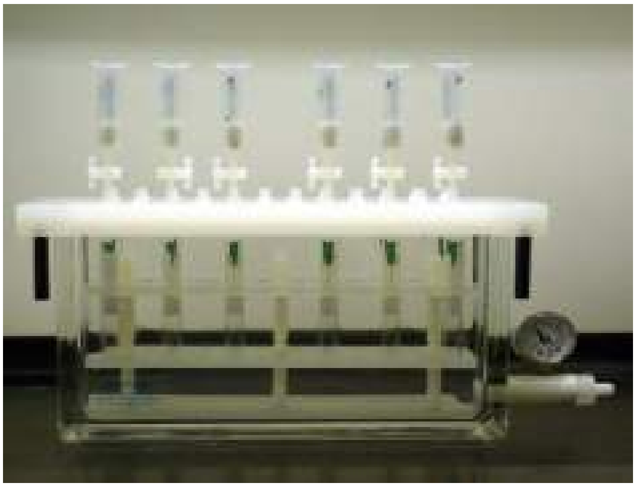

Figure 8.6: Typical Solid Phase Extraction Setup

Liquid–liquid extraction (LLE) is used for extraction of POPs from water, blood and milk. Liquid samples are often adjusted to neutral or slightly acidic conditions prior to their extraction, because alkaline conditions may cause decomposition of some OCPs, such as endosulfan and endrin. A modified LLE method, known as dispersive liquid–liquid micro extraction (DLLME), is simple and rapid, and consumes considerably less solvent, and is therefore more environment-friendly (Herrera-Herrera et al., 2010; Zhao et al., 2012).

Clean-up

Most clean up procedures use combinations of silica, alumina, Florisil® and carbon adsorbents or size exclusion materials (e.g. gel permeation chromatography) to remove co-extracted pigments, low molecular weight lipids and other interferences (Spinnel et al., 2008; Subedi and Usenko, 2012). However, utmost care must be taken in case of many pH sensitive analytes such as some OCPs and halogenated flame retardants.

8.3 Instrumental Analysis

There are a few studies carried out by different group of scientists on new POPs such as: PBDEs, OCPs, PFAS, PFOS, PCNs, Pentacholoro-phenols, SCCPs in various matrices such as soil, air, water, human blood serum, household wastes, electrical and electronic wastes, sediments, biota, dust samples. The extraction methods vary from Soxhlet to microwave assisted methods to ultrasonic and other methods. The instruments used range from GC-MS to GC-ECD and GC-HRMS and HPLC.

Chapter 9

ENVIRONMENTAL AND HEALTH IMPACT OF POPs

9.1 Introduction

The impacts due to Persistent Organic Pollutants (POPs) on the environment and humans have been observed globally. Although different categories of POPs have different impacts, overall, it is indicated that exposure to POPs can result in endocrine disruption, reproductive and immune dysfunction, brain and nervous system disorders, developmental disorders, and cancer (POPs Toolkit - Health Implications, n,d.). Some organochlorine chemicals are likely carcinogenic by promoting the formation of tumours.

POPs are used as pesticides or industrial chemicals in different applications, such as agriculture, textile, plastic production. It is released as a by-product during combustion or any industrial process. Their long-range transportation, persistence and impact is seen in pristine Arctic regions, thousands of miles from any known source. The Stockholm Convention, adopted in 2001 made procedures to keep identifying more POPs, which are harmful to the environment and human health, and to keep expanding the list. At present, the Convention has listed 30 POPs, which needs to be phased out/restricted or controlled in the countries party to the Convention.

9.2 Environmental Impacts

POPs are known to cause detrimental environmental impacts for more than three decades now. A number of studies have linked POPs exposures to declines, diseases, or abnormalities in a number of species of fish, birds, and mammals. POPs are organic chemical compounds, which means that they have a chemical structure that contains carbon and hydrogen. They share five particular properties in common: Persistence, Bioaccumulation, Long-range atmospheric transport (LRAT), Adverse effects, Semi-volatility.

Since POPs are present across the environment, they find their way up in the food chain and can thus be found in food products including crops. Having the properties which make them bioaccumulate and bio magnify, they enter the biota through the water/soil/sediment/air, and get deposited in their bodies. They further bio-magnify and reach the organisms that consumes them, and they transfer to the egg or the baby from the mother.

Globally, the presence of POPs is being studied during the last 30 years, these POPs chemicals been found in different environmental parameters, including aquatic and terrestrial species. A study observed severe liver damage in trout with 0.79 to 5.5 g/g Short-chain chlorinated paraffins (SCCPs) in whole fish tissue (POPRC-4, 2008). In India, many detrimental environmental impacts of POPs have been recorded since a long time. DDT for instance, was found in several water bodies, drinking water, soil and even different life forms including fish, worms, bats and birds (Toxics Link, 2011). In 2009, the pollutant was

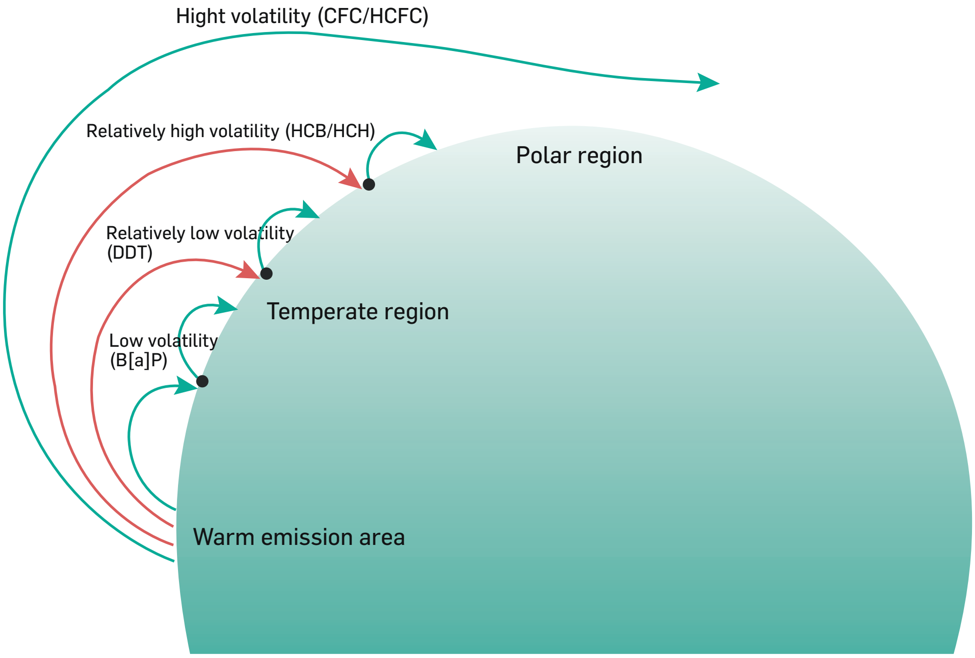

Figure 9.1 Global Fractionation Hypothesis or the Grasshopper effect (*Source: AMAP Assessment, 2002*)

detected in Gomti River in concentrations ranging from 6–476 ng/l (Malik et al., 2009), and Kaveri river in the range 1750-2430 ng/l in the same year. In 2012, It was found in Ganges in the range 61–230 ng/l (Sharma et al., 2014). It has similarly been detected in ground water, soil samples etc.

9.3 Human Health Impacts

POPs have been known to cause detrimental impacts on the human health. Evidences of the availability of POPs in humans have been found since 1960s, when Rachel Carson in her book Silent Spring pointed out how the extensive usage of DDT as a pesticide has disrupted ecosystems, and caused a number of diseases in humans including cancer. Recent epidemiological studies have also linked exposure to POPs to the development of metabolic diseases like type 2 diabetes and obesity (Ruzzin, 2012). They further have the property of crossing the placental barrier and thus can contaminate the fetus if exposed to a pregnant woman (Tang et al., 2020). Being endocrine disruptors and known of a number of reproductive, neurological and developmental disorders, they put the growing child at a high risk leading to a variety of disorders including brain and nervous system impairment, cancer and tumor induction in infants (POPs Toolkit - Health Implications, n.d.) even threatening its life. Exposure during development has been linked to reduced immunity (and increased infections), developmental abnormalities, brain and nervous system impairment, and cancer and tumour induction or promotion in infants and children (POPs Toolkit - Health Implications, n,d.). There may also be a link to human breast cancer.

Apart from severe impacts on the fauna and flora they contaminate, they have toxic consequences in humans through dietary intake of POPs contaminated dairy products, fish, eggs, meat etc, Having the ability to bio-magnify, POPs are readily absorbed in fatty tissue, where concentrations can become magnified by up to 70,000 times the background levels (SC-POPs, 2004). Another set of unintentional POPs, which are called dioxins and furans, have severe health impacts. As per the World Health Organization (WHO, 2008), dioxin is known to cause peripheral neuropathies, fatigue, depression, personality changes, hepatitis, enlarged liver and abnormal enzyme levels. Similarly, PCBs are known to have carcinogenic, reproductive, neurological, developmental, respiratory and immune-toxic impacts on humans. They can also reportedly cause liver toxicity. There are evidences linking the following human illnesses and disabilities to one or more of the POPs (CHE, 2019).

The first POPs linked with direct impacts on the human health was DDT. It has the potential to suppress human immune system, it also produces oestrogen-like alterations of reproductive development, and there is also limited data that suggest a possible association between DDT (and its metabolite DDE), and the risks of breast cancer. International Agency for Research on Cancer (IARC) has also classified DDT as a possible human carcinogen (Group 2B).

Global studies have documented the presence of POPs in human blood, urine, breast milk, serum and tissues (AMAP Assessment, 2015). As per WHO (WHO, 2008), PCB residues in adipose tissue of the general population in industrialized countries range from <1 to 5 mg/kg, on a fat basis and the average concentration of total PCBs in human milk is in the range of 0.5 to 1.5 mg/kg fat, depending on the donor's place of residence, lifestyle, and the analytical methods used. The AMAP assessment, 2015 detected various POPs such as HCB, Mirex, PFOS (perfluorooctane sulfonate), PFOA (Perfluorooctanoic acid) in maternal and infant blood in Alaska. Similarly, the report detailed bio-monitoring data of many POPs in artic regions indicating the presence of these chemicals in human body, even at the remote locations of the world.

9.4 Human Exposure to POPs

Humans can be exposed to POPs and other hazardous substance through diet, occupation, accidents and both the indoor and outdoor environments. Exposure to POPs can either be a short-term exposure to high concentrations (acute) or long-term exposure to lower concentrations (chronic). Acute exposure to dioxins and furans can occur during herbicide production, industrial accidents, chemical fires, or through the burning of waste. In addition, exposure to chlorinated pesticides can occur both from accidental ingestion of treated seeds or via poor handling or application processes.

Chronic exposure occurs most commonly via dietary exposure pathways. Due to their tendency to bio-accumulate, longer-term human exposure to the POPs as identified in the *Stockholm Convention* is generally via food.

Evidences of the presence of different POPs (majorly DDT, HCH, PCBs) in human body have been found across the globe. In India, very high levels of DDT have been reported in human fat tissues. Dieldrin and aldrin have been detected in Delhi, while PCB, dioxins and furans have been detected in southern part of the country. Studies in Uttar Pradesh have revealed that DDT levels in blood of people (who were occupationally exposed to DDT as part of malaria control) were significantly higher than that in groups who were not so exposed (Dua et al., 1998).

9.4.1 Risk of Cancer from POPs exposure

The International Agency for Research on Cancer (IARC) identifies most of the 12 POPs targeted by the Stockholm Convention as presenting a potential carcinogenic risk to humans.

9.4.2 POPs (Used in Plastic products) and its impact on the environment and human health

According to their usage and release, POPs fall into two categories: Intentionally produced or unintentionally produced. Some of the POPs are also used in the production of different types of plastics and/or its products. This leads to leaching of these chemicals from the products. Since, many of these plastics are also used to keep food products, these POPs leach into the food items and thus enter the human body and can therefore cause health implications. In different parts of the world, there are also concerns about the recycling of POPs containing plastics to produce toys and many other children's products. The usages, environmental impacts, and human health impacts of the intentionally and unintentionally produced POPs are summarized in this chapter.

9.5 The Socioeconomic analyses of regulating POPs in India

Prudent economic analyses of regulatory measures for harmful substances require that external damages and the associated costs be considered for socioeconomic analysis when making decisions. The cost-benefit analysis (CBA) provides a standard framework for comparing the costs and benefits of policies, programs and projects that entail health and environmental impacts. However, for substances that are persistent, bio accumulative and toxic (PBT) such as PFOA and PFHxS, the cost-benefits assessments face some challenges (Oosterhuis et al., 2017), as are persistence and bioaccumulation can occur far away in terms of space and time from their source it is extremely very difficult to predict and quantify the public health and environmental impacts of these substances.

The costs associated with the regulation of PBTs and very Persistent and very Bio-accumulative (vPvB) substances are many and these costs are discussed by Oosterhuis and Brouwer (2015). It is important to note that the costs may not only entail additional expenditure, but also reduced benefits/welfare and indirect costs associated with PBT control such as loss of competitiveness, etc. The measurement of costs of substitution depends on the extent to which the substitution may require changing the production process.

A few studies have estimated the socio-economic costs of PFAS pollutions, where the socio-economic analyses of regulating POPs are sketched in RPA (2019) and Goldman et al. (2019). The main results of the socio-economic costs of the PFAS are summarized. RPA (2019) builds on risk profile of PFHxS, its salts and related substances to present a background information relevant to the Risk Management Evaluation of these substances under the Stockholm Convention. Although RPA (2019) dwells on producers and users of PFHxS and related substances and reduction potential of global regulation, the emphasis of this analysis will be on the socio-economic analyses benefits and costs of global regulation and economic feasibilities for waste handling and clean-up of contaminated sites.

Further to estimate both the impact and monetary costs of inaction on PFAS, Goldman et al. (2019) establish framework for estimating the socioeconomic costs of PFAS on human health and environment. This is achieved through the adoption of the impact pathway framework for assessing the socio-economic costs of restricting PFAS at different degrees of exposure.

The impact pathway framework is simplified in Figure 9.2.

The human health and environmental impacts can be valued through revealed preferences and stated preferences studies that are designed specifically for the estimation of these impacts. However, in most cases these specific studies are not available, and one must conduct value transfer which transfer estimates from study site to policy sites. Navrud (2017) identifies three techniques of value transfers and these are unit value transfer, value function transfer and meta-analysis. For the purposes of this review, the simplest value transfer is opted, which is the unit value transfer and it is derived as:

$$B_p = B_s \left(Y_p / Y_s \right)^{\beta}$$

where B_p is the adjusted benefit estimate for new location, B_s is the original estimate from study site, Y_p and Y_s are the income levels at the new location and study site respectively and β refers to the elasticity and this is usually assumed to be between 0.4 and 1.0. Jacobsen and Hanley (2009) found that GDP/capita (i.e. societal income) was a better predictor of WTP than respondents' income, which simplifies the calculations. For the purposes of this report, adjustments will be made using the purchasing power parity (PPP) for which PPP data are assessed from OECD. The main advantage of using the PPP is to adjust for differences in purchasing power parity.

The estimation of costs of inaction linked to the exposures to PFAS is grouped into two. These are health-related costs of exposure to PFAS and non-health costs of environmental contamination with PFAS.

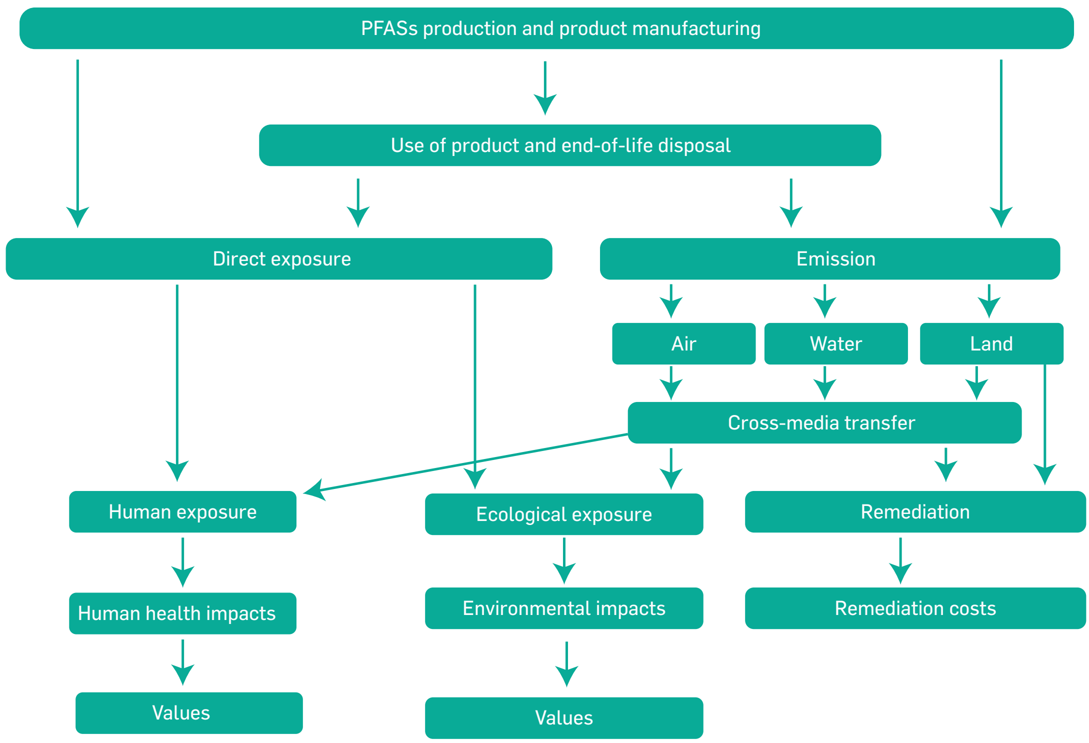

Figure 9.2: The pathways linking PFAS to health and environmental impacts and values/costs (*Source: Based on Goldman et al. (2019*)

Chapter 10
INTERNATIONAL REGULATORY FRAMEWORKS AND BEST PRACTICES IN MANAGEMENT OF POPs

10.1 International Regulatory Frameworks, Policies and Programs for POPs management

Stockholm Convention: The Stockholm Convention on Persistent Organic Pollutants (POPs) was adopted in May 2001 and came into force on May 17, 2004. India ratified the Convention on January 13, 2006 and came into force on April 12, 2006. Subsequently, in 2011, India prepared a National Implementation Plan to conduct an assessment and prepare an implementation plan for controlling the old twelve POPs. Among others, the provisions of the Convention require each party to prohibit, restrict, reduce and eliminate specific POPs that are listed in different Annexes to the Convention (http://www.pops.int/; Overview of Stockholm Convention). Currently, the Convention has listed 30 POPs, the latest addition being Dicofol and perfluorooctanoic acid (PFOA). The Convention has a POPs Review Committee which reviews the characteristics of POPs and then takes further decision for whether it should be recommended for listing.

Rotterdam Convention: Rotterdam Convention was adopted in 1998 to promote shared responsibilities related to import of hazardous chemicals and pesticides. It promotes international efforts to protect human health and the environment. The Convention entered into force in 2004, with the various key objectives (www.pic.int; History of the negotiations of the Rotterdam Convention). The convention covers several POPs, which are also regulated under Stockholm Convention such as Aldrin, DDT, Chlordane, Dieldrin, Endosulfan, Lindane, Hexachlorobenzene and Toxaphene (under Annex III), banning or restricting them for health and environment reasons. These are further subjected to the Prior Informed Consent (PIC) procedure (www.pic.int; Overview of Rotterdam Convention). India ratified to the Rotterdam Convention on May 24, 2005 and entered into force on August 22, 2005.

Basel Convention and Basel Ban Amendment: The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal was adopted in 1989 and entered into force in 1992. (Basel Convention, n.d.). India signed the Basel convention in June 1992 and ratified in September 1992. However, India has not ratified the Basel Ban amendment yet. In 1995, the Amendment to the Basel Convention ("the Ban Amendment") was adopted during the third meeting of the Conference of the Parties that prohibited all transboundary movement of hazardous wastes.

10.2 Other International Governance Initiatives for POPs management

Strategic Approach to International Chemicals Management (SAICM): SAICM is a non-binding global policy framework adopted in 2006 to achieve sound management of chemicals throughout their life cycle so that by the year 2020, chemicals are produced and used in ways that minimize significant adverse impacts on the environment and human health (www.saicm.org; SAICM overview). The SAICM Secretariat is hosted by the UNEP. India agreed to the SAICM in February 2006. The Ministry of Environment Forest and Climate Change (MoEFCC) is the SAICM National Focal Point in India, which coordinated and engaged with all relevant stakeholders (including government, civil society, academia and industry) when formulating legislation for the sound management of chemicals and chemical waste in India.

EU developments on management of POPs: The European Commission (EC) ratified the Stockholm Convention on 16 November 2004 declaring its support to the Convention's objective. (https://ec.europa.eu/; POPs). The European Chemicals Agency (ECHA) of the European Union (EU) manages the technical and administrative aspects of the implementation of the EU regulation called REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals). It entered into force on 1 June 2007. The POPs Regulation (ECHA, 2018) is the EU's effort to implement the SC and the Convention on Long-Range Transboundary Air Pollutants (CLRTAP) on POPs. The POPs Regulation contains four annexes that list substances which are covered by specific provisions (Swedish Chemical Agency, 2017). On 26 August 2010, several amendments of the EU Regulation entered into force. The new chemicals listed are: 4 types of polybromodiphenyl ether (PBDEs), alpha hexachlorocyclohexane (α-HCH), beta hexachlorocyclohexane (β-HCH), perfluorooctane sulfonic acid (PFOA), its salts and perfluorooctane sulfonyl fluoride and pentachlorobenzene (PeCB). (https://ec.europa.eu/; POPs). In 2019, the EU published Regulation (EU) 2019/1021, recasting the POPs Regulation ('POPs Recast Regulation'). This new law contains several important changes to the POPs Regulation (European Union, 2019). Under this new Regulation, definitions are clarified and aligned with REACH Regulation (EC) 1907/2006 and Waste Framework Directive 2008/98/EC. In particular, substances, mixtures (previously the "preparation" was used) and articles' definitions are aligned with REACH (TUVSUD Newsletter, 2019). The EU has also developed an Union Implementation Plan (https://ec.europa.eu/; International Conventions) (June 2014), which lays down a strategy and action plan for further Union measures related to POPs included in the Stockholm Convention.

Developments of REACH regulation to manage POPs: Entered into force in 2007, REACH is a regulation of the European Union, adopted to improve the protection of human health through the better and earlier identification of the intrinsic properties of chemical substances. (https://echa.europa.eu/; Understanding REACH). REACH has three major lists for regulation, restriction, and authorization: a) REACH SVHC (Substances of Very High Concern) (REACH SVHC List, 2020) consisting of POPs such as PFOA, DecaBDE, HBCDD, etc. b) REACH Authorization list (Annex XIV) (REACH Authorization List 2020) consisting of 43 substances. c) REACH Restricted Substance List (Annex XVII) (REACH Restricted Substance List 2020) consisting of 70 substances.

10.3 POPs management in developing countries

China: China signed the UN Stockholm Convention in May 2001, ratified it with an opt-in clause in June 2004, and issued the NIP in April 2007 (UNEP-POPS-NIP-China, 2007). For the initial group of 12 POPs, the NIP set objectives in stages and by region and industry for Convention implementation, developed implementation measures and specific action plans, and made action objectives in detail for the first stage (by 2010), the second stage (2010-2015) and the long-term future**.** The country submitted its second NIP in 2018. By December 2017, the number of POPs restricted and controlled in China according to the Convention and its amendments increased from 12 to 23. (UNEP-POPS-NIP-China-COP6, n.d.):

Indonesia: Indonesia is not a pesticide producing country and Government Regulation No. 74 of 2001 regulates their import ban. At present, neither export data on pesticides is available, nor is there any information on stockpiles. DDT has been banned in Indonesia and was never registered as a pesticide.

Indonesia signed the Stockholm Convention in 2001, ratified it in 2009, and finalized its NIP for 12 initial POPs in 2008. They further updated their NIP to accommodate the newly added POPs in 2014. The current regulations mainly govern some of the chemicals and pesticides under POPs. There are three POPs whose life cycle stages are not regulated namely PFOS and related substances, PBDEs, commercial octaBDEs, and HBCDDs (UNEP-POP-NIP-Indonesia, 2008). Indonesia does not have regulations on four of the newly added POPs.

Brazil: Brazil signed the Convention in 2001, ratified it in 2004, and submitted its NIP in 2015. Since 1970s, many regulatory orders restricted the use of POPs. In 1998, DDT was excluded from the list of substances that could be used in agriculture and household cleaning. From 2002 to 2003, several pesticides suspected of having adverse effects on human health were re-evaluated and were restricted. Heptachlor was banned. In 2006, a new assessment was carried out resulting in a ban on Lindane. In 2010, endosulfan was declared to be withdrawn from the Brazilian market over three years — import ban as of 2011, manufacture on Brazilian soil banned as of 31 July 2012 and ban on trade and use as of 31 July 2013. Currently, all POPs pesticides are banned in Brazil. The country has not made use of the specific exemptions approved by the Conference of the Parties for aldrin, chlordane, DDT, dieldrin, endosulfan, heptachlor, lindane, mirex, hexachlorobenzene and pentachlorobenzene (UNEP-POPS-NIP-Brazil, 2015)

10.4 BAT and BEP as instruments for controlling POPs pollution

For the management of POPs, there is a need to implement Best Available Techniques (BAT) and Best Environmental Practices (BEP) by adopting appropriate prevention and release reduction measures including the promotion of alternatives.

10.4.1 BAT/BEP in Stockholm Convention for POPs

The SC promotes the use of BAT and BEP for preventing releases of POPs into the environment. Article 5 of the SC requires countries to develop, within two years of their entry into force, an action plan to identify, characterize and address the release of chemicals listed in Annex C. The SC guidance document for BAT/BEP describes the chemicals listed in the Convention's Annex C and describes the main provisions and requirements under the Convention as well the Basel Convention. The guidance document has been prepared describing how to identify and quantify formation and release to air, water, land, products, and residues, which allows the development of complete and comparable inventories. This chapter includes the general considerations in determining best available techniques, keeping in mind the possible costs and benefits of a measure and consideration of precaution and prevention of POPs. The general reduction measures that could be considered in determining best available techniques for facilities that that have similar usefulness, but which avoid the formation/release of such chemicals have been listed in this chapter. The Conference of the Parties may develop guidance regarding best environmental practices. The SC Guidelines on BAT/BEP document provides guidelines on BAT/BEP relevant to Article 5 and Annex C of the SC on POPs of the various source categories. The industrial source categories that have the potential for comparatively high formation and release of these chemicals to the environment have been included in this chapter. Based on SC on POPs, the general prevention measures relating to both BAT and BEP that can be adopted to prevent the formation and release of the select chemicals is also listed.

10.4.2 BAT guidance in CLRTP Protocol

The United Nations Economic Commission for Europe (UNECE) adopted the Protocol on POPs in Aarhus (Denmark) on 24 June 1998. It focuses on 16 substances comprising 11 pesticides, two industrial chemicals and three by-products/contaminants. In December 2009, as part of the UNECE Protocol on POPs, the Executive Body for CLRTP (UNECE, 2009) presented the guidance document for BAT to control emissions of POPs from major stationary sources. The document describes control techniques for reducing emissions of dioxins/furans and PAHs (polycyclic aromatic hydrocarbons) from major stationary sources.

10.4.3 BAT Reference Document

The European Integrated Pollution Prevention and Control Bureau (EIPPCB) produces reference documents on BAT, called BREFs (Best Available Techniques Reference documents) that are the main reference documents used by authorities while issuing operating permits for installations that represent a significant pollution potential in Europe. This section summarizes the BREF Document for treatment of waste containing POPs. It states that for installations for the treatment of waste containing POPs, incineration, amongst others, is the most widely used technology for PCB destruction. Also, it states that the application processes and techniques (European IPPC Bureau, 2018) for treatment of POP-containing waste include decontamination of waste or equipment polluted with POPs before reuse, recycling or disposal, and decontamination of PCB-containing waste. For treatment of wastes contaminated with POPs, mixing and blending of wastes for recovery could be allowed if the concentration of POPs does not exceed the low POP contents, as defined in the Basel and Stockholm Treaties and in Regulation (EC) No 850/2004 of the European Parliament.

10.5 National Implementation Plan: BAT/BEP in India

The environmental legislation in which the BAT policy is embedded are: The Environmental (Protection) Act & Rules, 1986; The Water Act, 1974; The Air Act, 1981, etc. India submitted the NIP on the first 12 POPs in April 2011. The Ministry of Environment, Forests and Climate Change (MoEFCC) is responsible for the implementation of NIP over a period of 12 years from 2011-2022. CSIR-NEERI of India was endorsed as Stockholm Convention Regional Centre (SCRC) on POPs for Asia Region in April 2011, and serves India and ten Asian countries (for capacity building and technology transfer). An expert group of CSIR-NEERI in January 2020 (NEERI, 2020) identified a list of critical components on BAT/BEP, and a working group from various organizations developed a specific work plan. The two most important sectors targeted to promote the use of BAT/BEP are the waste incineration and ferrous and non-ferrous industries. The NIP aims to promote technology transfer and investment by identification and implementation of innovative mechanisms for waste management through a) Immediate priorities and proposals (2011-2013); b) Medium term priorities and proposals (2012-2022); and c) Long term priorities. The MoEFCC, Central Pollution Control Board (CPCB), CSIR-NEERI, industry-specific Task Forces and the Peer and Core Group Committee (expert groups) are the key actors in charge of information collection and evaluation of techniques for POPs management. National Institute for Interdisciplinary Science and Technology

(NIIST), Thiruvananthapuram has established the first dioxin research laboratory in India and contributed to the preparation of NIP (NIIST, n.d.). In 2018, the UNEP with support of MoEFCC have formed an expert group (with organizations like SRM University, Mu Gamma Consultants Pvt Ltd., TERI, and Toxics Link, CSIR-NCL, IIT Bombay, CSIR-NIST etc.) to strengthen the institutional capacity for the sustainable management of POPs.

10.6 Review of BAT/BEP strategies for India's newly restricted POPs

India notified the Regulation of Persistent Organic Pollutants Rules, 2018 that will ban the manufacture, trade, use, import and export of the seven toxic chemicals listed under the SC that belong to Annex A category of SC except PeCB and HCBDD that belongs to both Annex A and C. This section provides a review of BAT/BEP strategies of the new POPs, and provides details of the phasing out process Hexabromodiphenyl ether and heptabromodiphenyl ether, Tetrabromodiphenyl ether and pentabromodiphenyl ether, Chlordecone, Hexabromobiphenyl, Pentachlorobenzene, as per the UNEP Regional Plan, 2012. The SC has listed HBCDD with specific exemptions for production and use in expanded polystyrene (EPS) and extruded polystyrene (XPS) in buildings. The alternatives to HBCDD are described in this chapter; for example, a mechanical alternative for HBCDD would be an encasing of EPS or XPS into fireproof casings but is only limited to a few applications. The techniques for determination of BAT/BEP for production and use of HBCDD (UNEP, 2017) have been summarized in this chapter. The different considerations for the environmentally sound management of wastes containing HBCDD have also been included. Lastly, the chapter mentions about a guidance toolkit for POPs-contaminated site investigation and management that was developed by the United Nations Industrial Development Organization (UNIDO) Expert Group on POPs. This Toolkit includes generic guidance for the development of suitable technologies for land remediation in relation to BAT/BEP. It is a training tool and self-directed manual (UNIDO, n.d.) for decision-makers, practitioners, and other stakeholders that focuses on the initial twelve POPs and entails five main modules.

Chapter 11
OVERVIEW OF USE AND RELEASE SOURCES OF THE 7 NEW POPs

This chapter provides an overview of the use, emission sources, presence in waste and release sources of the seven POPs newly ratified by the Government of India, listed under the Stockholm Convention (SC), namely Chlordecone, Hexabromobiphenyl, Commercial octa-BDE, Commercial penta-BDE, Pentachlorobenzene, Hexabromocyclododecane and Hexachlorobutadiene.

While production containing the POPs addressed under the SC have been phased out in many countries since the mid-2000s, there are concerns over export of electronic waste products to developing countries leading to chemical releases during recycling operations without adequate emission controls. Moreover, there are limited available information for the status of production, use and release of the assessed POPs from developing countries and transitioning economies.

11.1 Chlordecone

Chlordecone is a synthetic chlorinated organic compound which has mainly been used as an agricultural insecticide, miticide and fungicide. Production and use of chlordecone has ceased over the last decades in developed countries, and available information suggests that it is no longer produced or used. However, it is assumed that Chlordecone is still produced or used as an agricultural pesticide in some developing countries, which may ultimately be released to the environment. Given that the use of Chlordecone has phased out and was mainly used as an agricultural pesticide, waste is presently not considered a major source of Chlordecone. However, there is a possibility of unknown sources of use that may produce Chlordecone containing waste.

Dust containing chlordecone has been observed to disperse into fine particles and spread 60 miles from a point source. Main routes for the transportation of Chlordecone is adsorption to particles in the ocean currents and inside organisms (biotic transport).

Chlordecone is highly persistent in the environment, as it is not expected to hydrolyse or biodegrade in aquatic environments and soil. Chlordecone is considered to have a high potential for bioaccumulation and biomagnification. It has a potential for sorption to particulate matter (dust, soil and sediment) and organic material (living organisms). When bound to organic-rich soil, Chlordecone is highly immobile; however, when adsorbed to particulate matter in surface water, Chlordecone can be transported great distances before partitioning out to sediment. Thus, surface water from Chlordecone containing waste might cause releases of the pesticide to the environment.

11.2. Hexabromobiphenyl (HBB)

Hexabromobiphenyl (HBB) belongs to a wider group of polybrominated biphenyls (PBDEs) and is a component in technical polybromobiphenyls (PBBs). The commercial production of PBBs began in 1970, where it typically was used as a fire retardant in three main commercial products; acrylonitrile-butadiene-styrene (ABS) thermoplastics for constructing business machine housings and in industrial (e.g. motor housing), and electrical (e.g. radio and TV parts) products; as a fire retardant in coatings and lacquers; and in polyurethane foam for auto upholstery.

At the time of the SC proposal, no information of potential production was available for developing countries or transitioning economies. Thus, it cannot be excluded that HBB is still in production or in use in some of these countries. Available information suggests that the production and use of HBB ceased in the years previously to the SC proposal. Given electric and electronical products' expected lifetime of 5-10 years, it is anticipated that HBB containing products have already been disposed of. However, it is still important to identify and manage articles and wastes that may contain HBB.

Release into the environment during normal production could occur via emission into the air, in waste waters, solid losses to landfills resulting from drying, handling, shipping and transportation, and losses to the soil. However, assuming that the chemical is no longer produced, the releases to the environment must be associated to historical processes, as well as to releases during the service life of articles containing the commercial mixtures and at the end of article service life during disposal operations.

HBB can enter the environment from the widespread use of flame-retarded products. Control measures in the treatment of Waste Electric and Electronic Equipment (WEEE) are key to prevent HBBB leakage (EC Directive 2002/96/EC). There are concerns over export of electronic waste to developing countries leading to HBB releases during recycling operations without adequate control measures. Burning or incineration of HBB-containing waste could lead to formation and release of brominated dibenzo-p-dioxins and -furans. Control measures for releases of HBB should also be considered in the context of plastics which is recycled or disposed of in landfills (OSPAR 2001).

11.3 Commercial octa-BDE

Commercial Octa-BDE (c-OctaBDE) has been used as an additive flame retardant mainly in the plastics industry for polymers for electronic equipment (typically office equipment and business machines). Globally 70% of c-OctaBDE has been used in acrylonitrilebutadiene styrene (ABS). Other minor uses include high impact polystyrene (HIPS), polybutylene terephthalate (PBT) and polyamide polymers. Information suggests that the use of c-OctaBDE has been phased out since the mid-2000s and is no longer produced in the EU, USA and the Pacific Rim. There is no available information to indicate whether it is still being produced in developing countries.

Although the c-OctaBDE seems to be no longer produced, releases during the service life of articles containing the commercial mixtures are still relevant, particularly at the disposal of products containing c-OctaBDE. Emissions from use, disposal and recycling of products containing c-OctaBDE are particularly difficult to control. According to estimates from the EU, the releases of OctaBDE from products enter industrial or urban soil and dust (75%), air (0.1%) and surface water (24.9%). Possible long-term increases in levels resulting from releases at waste sites should be noted. There are concerns over export of electronic waste to developing countries leading to c-OctaBDE releases during recycling operations. In addition, burning or incineration of c-OctaBDE-containing waste could lead to formation and release of brominated dibenzo-p-dioxins and furans (Leisewitz et al., 2000).

Wastewater and dust are considered major release routes of OctaBDE from waste. The SC outlines possible measures to reduce the environmental emissions of c-OctaBDE in recycling, recovery and disposal facilities. Companies could take actions like closing their systems for releases to the environment and dispose waste as controlled waste. Also, abatement technology could be installed at the site to ensure that potential emissions are captured (RPA 2002). However, this might not be applicable for all recycling sites; Especially in the informal waste handling sector such measures can be difficult to execute.

All sites handling c-OctaBDE-containing material should aim at minimizing dust and air emissions and avoid input to wastewater, by applying Best Available Techniques (BAT) or Best Environmental Practice (BEP) throughout the disposal, recycling and dismantling stages. Listing a substance under the SC implies a ban on recycling and reuse of stockpiles of c-OctaBDE. Because Octa-BDE could be present in articles used today (such as electronic articles, textiles and isolation materials), there is a need for national authorities to conduct surveys to get more detailed information about c-OctaBDE content in different articles becoming waste.

11.4 Commercial penta-BDE

Polyurethane foam has been the most common use (95-98%) of commercial pentabromodiphenyl ether (c-PentaBDE) since 1999 (Hale et al. 2002), and is mainly used for furniture, automotive and aviation industry. Other uses include rigid polyurethane elastomers in instrument casings, in epoxy resins and phenolic resins in electrical and electronic appliances, and construction materials. Up to the early 1990s, c-PentaBDE was used in printed circuit boards, usually FR2 laminates (phenolic resins) in Asia. Such FR2 laminates are used in household electronics (i.e. television, radio, video), vehicle electronics, white goods (i.e. washing machines, kitchen appliances).

Materials containing c-PentaBDE can cause slow release of c-PentaBDE to the environment. Some developing countries around the East China Sea are potential 'hot-spots' for releasing c-PentaBDE into the marine environment, as many industrial manufacturers of products containing c-PentaBDE are situated in coastal areas of Asian developing countries (Ueno et al. 2004). There are indications of a phase-out of c-PentaBDE in manufacture of new electrical and electronic products in the Asian region, yet the extent of this is uncertain.

C-PentaBDE is released into the environment during the manufacture, use and disposal of commercial products. Although production of c-PentaBDE is being phased out worldwide, products containing it will still be in use for several years to come, resulting in continuous releases into the environment.
Most of the c-PentaBDE is released as diffuse pollution during and after the service life of articles incorporating c-PentaBDE and as small-scale point source pollution from the waste management chain of the end products.

Major releases to air are emissions from products during use, through volatilization of PentaBDE and dust borne PentaBDE. Emissions of PentaBDE can also occur from recycling and dismantling activites such as dismantling of vehicles buildings and constructions. Emissions can occur from electronic waste recycling plants and shredding plants. Potentially toxic products such as brominated dibenzo-p-dioxins and furans might be generated during incineration of articles containing c-PentaBDE.

Flame-retardant treated polyurethane foam exposed to direct sunlight has also been demonstrated to disintegrate and release small, low density foam particles that may be transportable by stormwater runoff or air currents (Hale et al. 2002). Such degradation processes may provide an exposure route to organisms via inhalation or ingestion of the foam particles and their associated PentaBDE. Flame retardants emitted from products are likely to adsorb to particles, and these may adhere to surfaces within appliances, in the indoor environment, or spread to the outdoor environment during airing of rooms. While the use of c-PentaBDE incorporated in polyeurethane foam used in domestic and public furniture has been phased out in North America and Western Europe, detailed information on its use is lacking for many regions of the world.

Waste can be generated from production of c-PentaBDE, from processes for manufacture of c-PentaBDE-containing materials, and from end-of-life-service-life management of products containing c-PentaBDE. Most materials containing flame retardants are hard to dismount and segregate, thus becomes shredded and landfilled. Movement of polymer foam particles containing c-PentaBDE within landfills could transport the brominated material to leachate or groundwater. It is not currently possible to assess the significance of such processes.

Potentially toxic products such as brominated dibenzo-p-dioxins and dibenzofurans may be released during incineration of waste containing c-PentaBDE (Danish EPA, 1999). A continuation of WEEE export to Asian developing countries without adequate emission control and waste handling facilities is likely to remain a source of c-PentaBDE releases.

11.5 Pentachlorobenzene (PeCB)

The principal commercial use of pentachlorobenzene (PeCB) was as a chemical intermediate in the formation of the fungicide pentachloronitrobenzene (also known as quintozene). PeCB can also be found as an impurity in several other fungicides, herbicides and pesticides, and in dyestuff carriers. It may also have been used as a flame retardant. PeCB is presently only produced and used in relatively small amounts of analytical grade PeCB by laboratories for the preparation of standard solutions used for analytical purposes. Evidence suggests that PeCB is of no commercial significance with no reported trade or stockpiles. Data shows that production and use of PeCB in Europe and North America are negligible, but the situation in other parts of the world is less clear.

The most relevant diffuse sources of PeCB are solvents, pesticides, wood preservative products, uncontrolled combustion (i.e. barrel burning in open fireplaces), accidental fires and forest burning for agricultural purposes. The primary source of potential releases is by-product emissions dominantly associated with incomplete combustion of biomass, solid waste and coal. However, this conclusion is mainly based on data for Europe and North America. Although the production and use of PeCB seems to have ceased in most countries, its reintroduction remains possible. This could lead to increased releases and levels in the environment.

For PeCB formed as by-product in combustion processes there is a clear relation to PCDD/F releases formed by combustion. Most measures taken to reduce PCDD/F releases, as described in the Stockholm Convention's BAT/BEP guidelines for incinerators and other thermal processes, will lead to a significant reduction of the releases of PeCB.

In industrial chlorination reactions it is possible that PeCB is produced as a byproduct and it probably accounts for some of the emissions reported. PeCB formation has also been observed during combustion of municipal solid waste.

11.6 Hexabromocyclododecane (HBCDD)

Hexabromocyclododecane (HBCDD) is used as a flame-retardant additive, with the intent of delaying ignition and slowing subsequent fire growth during the service life of vehicles, buildings or articles, as well as while materials are stored (BSEF 2010). It was used as a flame retardant in a wide variety of articles, but mainly in expanded and extruded polystyrene (90%).

Most of HBCDD-treated polystyrene was used for insulation boards in buildings and vehicles. The second most important application is in polymer dispersion on cotton or cotton mixed with synthetic blends in the back-coating of textiles. Other applications include its use in high impact polystyrene for electrical and electronic equipment. HBCDD has been used and produced in all parts of the world and was the third most used brominated flame retardant in 2009. The global market demand for HBCDD nearly doubled from 2001-2011.

HBCDD may be released to air, water, soil and sediment during all stages of its life cycle. The largest releases are estimated to be to water from production of insulation boards, and to water and air from textile coating. Diffuse releases during the life cycle of insulation boards and textiles may also occur. Actually, emissions from HBCDD-containing materials will be a potential long-term source to the environment. Most of the produced volume of HBCDD ends up in in polystyrene (XPS, EPS) used in the construction and building sector. The use of HBCDD in insulation boards and the HBCDD built into buildings and constructions is increasing and it is likely that releases from EPS/XPS will be more significant in the future as an increasing number of buildings containing HBCDD will be refurbished or demolished. This turn-over will differ across regions, ranging from 10-50 years.

Recycled products containing HBCDD, are potential sources of emissions in the same way as virgin products. Recycling operations for recovery of metals or plastics in electronic products and vehicles are potential sources.

At the end of their service life, products containing HBCDD are likely to be disposed of in landfills, incinerated, recycled, or remain as waste in the environment. Wastes containing HBCDD are of concern because increasing amounts of HBCDD-containing wastes in landfills and other locations could be a long-term source of HBCDD emissions to the environment. Insulation boards form the majority of HBCDD containing waste.

Products and materials in landfill sites will be subject to weathering, releasing HBCDD particulates primarily to soil, and to some extent, water and air. High concentrations have been identified in Europe and in coastal waters of Japan and south China, near production, manufacturing, and waste disposal sites, including recycling, landfilling and incineration sites.

HBCDD containing products and articles are commonly recycled upon becoming waste. This can lead to HBCDD contamination of products that are difficult to identify. In developing countries, EE appliances containing HBCDD and other toxic substances are often recycled under conditions which results in a relatively high release of HBCDD to the environment and contamination of the sites (Zhang et al. 2009), and exposure of workers (Tue et al. 2010). Open burning and dump sites are common destinations for HBCDD containing articles and electronic wastes.

11.7 Hexachlorobutadiene (HCBD)

Hexachlorobutadiene (HCBD), either as a by-product from organic synthesis or intentionally produced, had various uses, including its employment as an intermediary in chemical or metallurgical industry, ingredient of heat-dissipating, insulating or hydraulic fluids and the application as a pesticide.

It was intentionally produced and applied as a solvent (for rubber and other polymers), as a 'scrubber' to recover chlorine-containing gas or to remove volatile organic components from gas, as hydraulic, heat transfer or transformer fluid, in gyroscopes (Lecloux, 2004), in the production of aluminum and graphite rods and as a plant protection product (WCC, 2002).

Worldwide production of HCBD has decreased considerably over the last decades and it is no longer produced in the UN-ECE region. Information about intentional production and use outside the UN-ECE countries is incomplete. Monitoring data from China (Li et al., 2008) and Taiwan (Juang et al., 2010) suggest that (by)production has continued at least until recently. The substance is still unintentionally released by industry, including during waste management.

Reduction and elimination of industrial emissions of HCBD may be achieved through modified processes and BAT and BEP methods which reduce and eliminate emissions of HCBD from chlorinated solvent production.

The main emission and discharge sources of HCBD are (a) unintentional release during the production of chlorinated hydrocarbons, (b) emission from disposed waste of chlorinated hydrocarbons, (c) emissions from other commercial uses and (d) emission from magnesium production. Currently, the most important known source of HCBD in the 27 EU Member States is the manufacture of chlorinated chemicals (particularly tri- and tetrachloroethene and tetrachloroethylene) through chlorolysis. HCBD is also commonly found accumulating in sewage sludge in urban waste-water treatment plants.

There may be substantial amounts of by-product formation from non-chemical facilities producing magnesium (UNECE 2007).

There is a crucial lack of information about by-production in non-UNECE countries. Reductions in the UNECE-region are expected largely due to technical investments in waste management and recycling facilities. However, the adoption of equally strict standards is not granted, and in fact is refuted by reports on current HCBD pollution in for example India.

HCBD releases can take place during waste incineration, and combustion sources of HCBD are similar to those of dioxins, furans and hexachlorobenzene. Currently, high temperature incineration is usually operated in developed countries as an emission control technique for residues from the production of chlorinated chemicals. Although incineration may be utilized in developed countries, it may not be the most cost-effective option in all countries. In some countries appropriate waste treatment facilities may not be available and additional costs may be incurred to store and ship wastes to treatment facilities abroad.

Hazardous waste disposal sites or industrial facility sites may also be potential release sources of HCBD. There is a need to determine ways to ensure better data collection and reporting of HCBD wastes and releases in order to track progress in reducing and eliminating these sources of contamination. Monitoring capacity for HCBD is needed in developing countries and transitioning economies. Particularly leachate monitoring and improved control and management measures plays a central role in the restoration and decontamination of waste disposal sites.

Chapter 12
ANALYSIS OF GAPS IN MANAGEMENT OF POPs IN INDIA

This report provides an overview of gaps identified across the chapters of the INOPOL baseline report. The purpose is to highlight existing limitations and challenges within monitoring and assessment methodologies of (POPs) with an emphasis on the project case study areas in India. INOPOL aims to address some of these gaps by providing state of the art science-based approaches, knowledge exchange, training and policy input to strengthen local and national capacity to ultimately mitigate the environmental threats posed by plastic and chemical pollution. The identified gaps have been compiled within analytical themes to demonstrate key areas where INOPOL may contribute to reducing gaps through knowledge generation, exchange and capacity building. The gap analysis is structured as follows: Data limitations, knowledge gaps, policy and regulatory gaps, infrastructure and capacity gaps, technological gaps and awareness generation gaps.

12.1 Data limitations

- There is a huge lack of data on the current levels of contaminants in the Indian environment, particularly of the 7 new compounds recently added by the Government of India to the list of POPs in the "Regulation of Persistent Organic Pollutants Rules, 2018". The extent of contamination for many of these notified compounds are unknown. With these data gaps, there is a constant struggle between stakeholders and authorities over the right course of action for steering the nation out of irreversible environmental damage. There is a great need for strengthening monitoring activities and capacities at local and national levels to fill these gaps (Chapter 3 and 6).
- The has assessed the stockpiles of some of the old POPs. However, there is no publicly available information on the status of how the stockpiles been stored and if these have been disposed of in an environmentally sound manner.
- The NIP has identified a number of POPs contaminated sites in India. Though the MoEFCC has developed an action plan to remediate the contaminated sites, information is not available on the status of these POPs contaminated sites.
- There is also a lack of data on the inventories of the 7 new POPs in India. In the study area Gujarat, which is a hub of chemicals, textiles, and automobile industries, there is a huge possibility of stockpiles of these industrial chemicals. However, information on the chemical quantities is limited. This baseline for the use and release of the 7 new POPs in manufacturing and production has revealed some of these key data gaps. Such information on the POPs in India is scarce, most data is only available from secondary sources, such as documentation from other countries in other parts of the world. In order to fill this gap, a coordinated effort on collecting data on production and use of the 7 POPs in Gujarat and India is needed (Chapter 3 and 11).

- The data on human exposure and health impacts of POPs is scattered. This correlation is difficult to analyse partly due to non-uniformity in the approaches and methodologies used across various studies (Chapter 8 and 9).

12.2 Knowledge gaps

- Much of the concern around microplastics is associated with their role in introducing persistent organic pollutants (POPs) into marine food webs. Some of the additives used to modify the properties of plastics are biologically active, potentially affecting development and reproduction. Microplastic and persistent organic pollutants (POPs) need to be studied in tandem to draw conclusions about their interlinkages and potential solutions for management of both. Considering the limited research for plastic-POPs interlinkages, the INOPOL project will provide a comprehensive and holistic view of both types of pollutants (Chapter 5).
- In working with the baseline report, gaps in the monitoring system by GPCB (Gujarat Pollution Control Board) and ULBs (Urban Local Bodies) has been revealed. This can be exemplified in a case from November 2019, when a private tanker was hired by a few chemical units located in Vapi for the dumping of hazardous waste in Surat. There have been a few such incidents where hazardous waste was been dumped in the drainage network or in the canal in the outer areas. Thus, a strengthening of monitoring capacity and coordination is needed (Chapter 4, 10).
- There is a lack in research studies on the health impact of the 7 POPs on local populations, especially workers working and living around the industrial estates. There is an urgent need for the identification of cost-effective monitoring techniques, mapping and clean-up programs for contaminated sites. The development of analytical methods for the new POPs are needed to provide reliable data for their environmental and biological occurrences, and for the investigation of their distribution, temporal and spatial trends, environment fates and potential sources. Such quantitative analysis-based monitoring not only helps stakeholders to share responsibility, but also provides vital information required by regulators (Chapter 4).
- Rivers are described and observed as important net sources of POPs to the marine coastal environment. However, quantitative assessments of rivers' role in POPs transport and release is still fragmentary, as measuring and monitoring POP discharge by rivers is a complex and costly operation. Environmental fate models are useful tools to overcome these limitations. Models capable of describing both the complex biogeochemical drivers and multimedia exchange in highly dynamic systems are vital for understanding POP transport and sources to marine coastal water in different rivers and under different conditions. The overall significance of riverine transport as a source of ocean pollution is still poorly understood, and is an important knowledge gap to fill (Chapter 7).
- Research studies in India have found the presence of PBDEs (OctaBDE, DecaBDE and HCBD) in various products, including childrens' toys in India. Studies have also found the presence of some of the POPs (largely Brominated Flame Retardants) in the plastic stream, which indicates cross contamination of banned chemicals in various products. These knowledge gaps should be addressed with large scale studies, as it is a public health concern (Chapter 9).
- A large population in India whose diets include fish, shellfish, or fatty food are particularly at high risk to chemical exposure. A study involving women from 50 countries by the Women's Environment and Development Organization (WEDO), reported reproductive health disorders in about 44% of the surveyed women, as a result of chemicals exposure in the workplace

(including e-waste recycling sites and landfills). The study also reported that other occupational health hazards have increased manifold (WHO, 1999). Similar studies are yet to be undertaken to assess the health status of the vulnerable population after adoption of the NIP.

- Chemical pollution has traditionally been regarded as the result of intentional and unintentional point source emissions from industry, agriculture and waste disposal. However, diffuse pollution sources in the landscape, as well as contaminant storage and remobilization from soils and sediments add enormous complexity to the task of assessing exposure and risk from both experimental and theoretical points of view. Developing tools for understanding and predicting the behaviour of chemical contaminants with multiple emission pathways and complex environmental behaviour is an essential step for prioritizing and implementing effective pollution management strategies (Chapter 8).

12.3 Policy and regulatory gaps

- The Union Cabinet of India has approved the ratification of seven chemicals listed under Stockholm Convention on POPs. The NIP for the new POPs needs to be developed, which will help to fasten the phaseout of these seven new POPs.
- Although India ratified the Stockholm Convention in 2006, challenges with implementation remain. For India, these issues are of emerging concern as both industrial pollution and improper waste handling is a major driver for marine litter and microplastics, where a potentially significant side effect is increasing loads of POPs. A largely informal and unregulated waste handling sector includes manual/mechanical recycling, open burning and mismanagement of electronic waste, responsible for large releases of POPs. The ship recycling industry is also a potential source of POP emissions. Although India recently updated its regulations on seven new POPs, lack of capacity remains a major obstacle in the development and implementation of plans and strategies for phasing out hazardous chemicals in the country (Chapter 1).
- In India, there are number of regulations in place to manage chemicals and to minimize the adverse impact of these chemicals on the environment and human health. However, these chemicals are categorized based on the nature of the usage, such as industrial chemicals and pesticides chemicals. Regulations of the industrial chemicals are within the purview of the EPA and are under the auspices of the Ministry of the Environment, Forest and Climate Change of the Govt of India. The regulation of the chemical pesticides is under the purview of The Insecticides Act, 1968 and is managed by the Ministry of Agriculture. Such differentiation in regulatory responsibilities creates challenges in implementing chemical regulations (Chapter 4, 10).
- As an extension of the previous regulatory gap, there is no exclusive authority in India to overview and harmonize the implementation of the Stockholm Convention (SC) in the country. The is the focal ministry for the SC. However, the Ministry of Agriculture and Farmers Welfare has the sole authority to make Rules on managing pesticides with regard to environmental contamination due to pesticidal POPs. Similarly, though there are other agencies like the Central Insecticides Board and Registration Committee (CIB&RC), it is the state agencies that have key roles in the overall management of pesticidal POPs in the respective states. There are also peripheral roles for several other bodies across the country. The Government of India does recognize their role in the overall POPs management in the country. However, the execution remains a challenge (Chapter 4).
- Implementation of SC at a global scale presents challenges linked, among others, to lack of

harmonization of processes and capacity in different countries. Hence, inventorying and curbing of primary sources of POPs is an actual ongoing challenge far from being completed (Chapter 6).

- A number of empirical studies in India has shown that food is an important exposure route to POPs. Yet there is no regulation in place to prevent contamination of the food chain by POPs.

12.4 Infrastructure and capacity gaps

- Laboratory infrastructure and human resource capacity are essential elements for POPs management in a country. In India, it has been observed that the infrastructure and capacity for POPs management is limited considering the magnitude of the problem. Although there are several laboratories in India with the capacity to measure POPs pesticides, many of these have limited capability and protocols in testing the industrial designated POPs. Knowledge exchange and capacity building in this field is needed (Chapter 4).
- The Government of India has issued stringent emission standards for Dioxins and Furans and certain regulations to monitor the POPs. The State Pollution Control Boards are key stakeholders in POPs management, but have limited capacity and infrastructure for monitoring POPs effectively. It has also been noted that ULBs tend to have a limited capacity to manage unintentional POPs, like the release of dioxins and furans from the burning of wastes (Chapter 4).
- In 2016, the Government of India issued the Solid Waste Management Rules (SWMR, 2016), in which it bestowed power with the municipalities to manage solid waste. But due to lack of infrastructure, waste is often not managed properly and amongst other problems, it leads to waste burning which is directly linked with the generation of dioxins and furans.
- Further, large Municipal Corporations in India are pitching for waste-to-energy plants where the dioxins and furans have evolved as a major concern. The SWMR, 2016 have specific emission standards for dioxins and furans from waste-to-energy plants, which adds pressure on the ULBs to adequately manage these POPs. However, there is a need to enhance ULBs knowledge and capacity to deal with the management of this complex issue (Chapter 4).

12.5 Technological gaps

- Although many types of incinerators have come up for managing various kinds of waste, there are very few laboratories in India that can measure and monitor the release of dioxins and furans. Also, the cost of the sampling and analysing these chemicals are very high (Chapter 4).
- Technological waste management infrastructure in India is mostly imported from Europe and North America. This becomes a challenge when the imported technology is not adapted to suit local conditions. Adoption of the Best Available Technology and Best Environmental Practices to mitigate the POPs may create local challenges. The incineration-based technology for the waste to energy plant set up in Okhla (Delhi) was emitting high quantities of Dioxins and Furans, for which the court had to intervene.

12.6 Awareness Generation gaps

- The NIP has outlined the need for public information, awareness generation and identified the role of key stakeholders to create awareness on the harmful effects of POPs. However, considering the size and population of the country, sufficient efforts have not been made in awareness on the health risks associated with POPs produced by open burning of the plastic waste releasing Dioxins and Furans into the atmosphere (Chapter 5).

- The report by Toxics Link Country situtaion report on POPs have revelaed that farmers are still using the banned pesticides such as DDT and Endosulfan. Moreover the banned POPs pesticides are being exported, imported and sold in the country. The farmers had no information about the ban of these chemicals for agricultural purposes.. There needs to be stricter rules and actions to bridge this awareness gap (Chaper 4).
- In India, the participation of industries towards management of POPs needs special attention as chemicals are largely deregulated in India. Many of the Indian industries are not aware of the developments of the Stockholm Convention and the risks associated with POPs, and in many instances argue against the listing of chemicals due to lack of awareness.

Chapter 13
WAY FORWARD

The INOPOL project will make result-oriented contributions to reduce chemical pollution, marine litter, and plastics pollution in India. The research commenced by developing a comprehensive baseline for pollution by Persistent Organic Pollutants (POPs). The compilation also gathered existing knowledge, data and research while identifying gaps within the spheres of management of POPs, thereby providing rich resources that has and will be used in project related activities. The baseline research followed and complemented the following activities:

- Developing a data collection strategy
- Developing a sampling and analysis strategy and its implementation
- Developing a monitoring strategy for POPs
- Developing policy notes and a POPs Management Strategy Report for Gujarat
- Capacity building, training, and outreach

Developing a data collection strategy

The data collected during the secondary research stage were fine-tuned and updated in accordance with inputs from stakeholder consultations. Primary data was also gathered through interviews, surveys, and collection of quantitative and qualitative environmental data.

Developing a sampling and analysis strategy

A standardized sampling and analysis strategy is important to collect data which is representable for the different environments (air, water, soil, biota) under investigation. The project aims to establish standard operating procedures (SOPs) for sampling of POPs contamination in different matrices. The project will also develop training materials to build knowledge and capacity of relevant stakeholders (e.g., officials of Pollution Control Boards, scientists, academicians) to conduct sampling and analysis of POPs (mainly the new POPs), including quality control and assurance measures.

In the present study, the key facts that were considered for selection of sampling sites were as follows:

- Catchment covering the upstream, mid-stream and downstream of the two river systems up to the tip of the estuary
- Hotspots along the urban and suburban transects such as industrial discharge areas, open dumpsite and pristine sites in wetland region and reservoir
- Passive Air Sampling (PAS) of plastic manufacturing as well as chemical factories' belt in Surat and Vapi in Gujarat.

The work plan for sampling of POPs includes the following:

- Levels and spatial distribution of POPs during post-monsoon/winter and monsoon/summer events
- Air-Water fluxes
- Sediment-Water fluxes
- Ecotoxicological risk associated with quantified POPs in surface water

Developing a monitoring strategy for POPs

Monitoring is a critical component in the management of POPs pollution and is a high priority issue with respect to both capacity building and implementation in India. The project will contribute to strengthening monitoring protocols, guidelines, and analytical methodologies, as well as training laboratory staff within the government and academic institutions in India. The development of extraction and analytical methods for POPs provides reliable data for their environmental and biological occurrences, and therefore plays an important role in the investigation of their distribution, temporal and spatial trends, environment fates and potential sources. Such quantitative analysis-based monitoring not only helps stakeholders to share responsibility according to the polluter-pays principle, but also provides vital information for facilitating data-driven decision making by regulators. The project will develop manuals and guidance documents for analysis of POPs, ready for application by government laboratories, institutions, and other relevant stakeholders.

Action plan for reducing use and release of new POPs in Gujarat

The accumulated knowledge arising from the project will be transformed into a format that is accessible and relevant for decision makers, thereby building capacity, awareness and providing actionable input to policy. This will continue throughout the project, with various publication formats for different target audiences (policy briefs, scientific commentaries etc.). The results will be ultimately synthesized into an 'Action plan for reducing use and release of new POPs' in Gujarat state.

Capacity building, training, and outreach

The key goal of the project is to build knowledge and capacity of different stakeholder groups, including experts and civil society, to reduce the releases of POPs and to better manage the impacts from POPs pollution. Adequate knowledge and awareness on POPs pollution will be generated through the training and capacity building programs of the project.
To ensure maximum outreach, the major project stakeholders have been divided into three different groups which will be targeted separately:

1. Policy makers, industry, and enterprise managers may need to take action against POPs pollution (including new POPs), and therefore must have a strengthened knowledge about different aspects of POPs pollution. *I.e. SPCB, CPCB, NEERI, MoEFCC, MoES, ULBs, industry associations and specific enterprises.*
2. Technical experts involved in the project or working with related projects. Particularly important are laboratory personnel (especially in SPCB and CPCB laboratories), who must have sufficient knowledge about the challenges in POPs analyses and state of the art knowledge, as well as experts working with environmental assessments, who need sufficient knowledge to evaluate the extent of a given problem (e.g., a contaminated site or an emission source). *I.e., SPCB, CPCB, MoEFCC, ULBs, NEERI, IIT Gandhinagar, research institutes, universities, and private laboratories*
3. The community who will benefit immensely from science-based and balanced information about POPs pollution, and related concerns. *I.e., NGOs, informal workers, and civil society in general.* Furthermore, engagement and co-produced research with stakeholders like NGOs, informal workers, government, industry, and civil society is important to map POPs networks, as well as identifying social and economic drivers, impacts and sustainable solutions.

The Roadmap

Under Project INOPOL, various aspects such as environmental occurrences, source identification, fate, and behavior of POPs in different environmental matrices will be included with case studies from India. Current research initiatives like the identification of cost-effective monitoring techniques and pollution control programs will also be included.

The training and capacity building programs will contribute to cover these aspects, to enhance capacity of stakeholders holistically on the ways and means to tackle POPs pollution and its impacts.

The INOPOL project will contribute to prevent and substantially reduce the scope of marine litter from land-based sources in the catchment areas of rivers Tapi and Daman Ganga in the State of Gujarat, which are highly affected by different industrial processes, chemical manufacturing, and resulting wastes. It is also a major receiver and transport route for POPs pollution. The knowledge and capacity of stakeholders, experts, and civil society would be enhanced for reduction of releases and of the impacts of plastic pollution and pollution due to POPs, which are the chemicals listed under the Stockholm Convention. By preventing and reducing marine pollution and hazardous waste in India, the project will contribute towards improving systems for POPs management from land-based sources; and recommend measures to manage waste from reaching the selected rivers; ensure sustainable production, use, and waste management within the private sector; thereby strengthening the national and regional instruments to prevent POPs pollution.

The project will thus also make contribution in the pathway towards the targets associated with few of the Sustainable Development Goals (SDGs) as they are directly related to chemicals and wastes; the targets such as 2.1, 3.9, 6.3, 11.6, 12.4, 12.5, 14.1 and 16.1. These targets also correspond directly to the strategies and work plans of the Basel Convention (1988), Rotterdam Convention (1998) and Stockholm Convention (2004), as well as their implementation targets and goals. The achievement of these SDGs can therefore provide a holistic and integrated framework for better coherence and a cross-sectoral approach to sound chemicals management across the paradigm, thereby addressing various aspects towards improved environment, health and well-being.

BIBLIOGRAPHY

1. Action Plan for Damanganga River. U.T. Administration of Daman & Diu. 2019. Retrieved from: https://daman.nic.in/websites/Pollution-Control-Committee/2019/Action-Plan-on-Damanganga-River-03-04-2019.pdf last accessed on April 9, 2021
2. AMAP, 2004. AMAP Assessment 2002: Persistent Organic Pollutants in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xvi +310 pp.
3. AMAP, 2015. AMAP Assessment 2015: Human Health in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. vii + 165 pp.
4. Anh HQ, Nam VD, Tri TM, Ha NM, Ngoc NT, Mai PTN, Anh DH, Minh NH, Tuan NA, Minh TB. Polybrominated diphenyl ethers in plastic products, indoor dust, sediment and fish from informal e-waste recycling sites in Vietnam: a comprehensive assessment of contamination, accumulation pattern, emissions, and human exposure. Environ Geochem Health. 2017 Aug;39(4):935-954. doi: 10.1007/s10653-016-9865-6. Epub 2016 Aug 19. PMID: 27542012.
5. Auta, Helen & Emenike, Chijioke & Fauziah, Shahul Hamid. (2017). Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects, and potential solutions. Environment international. 102. 10.1016/j.envint.2017.02.013.
6. Barnes, D. K. A., Galgani, F., Thompson, R. C. & Barlaz, M. 2009 Accumulation and fragmentation of plastic debris in global environments. Phil. Trans. R. Soc. B 364, 1985–1998
7. Beaumont NJ, Aanesen M, Austen MC, Börger T, Clark JR, Cole M, Hooper T, Lindeque PK, Pascoe C, Wyles KJ. Global ecological, social and economic impacts of marine plastic. Mar Pollut Bull. 2019 May;142:189-195. doi: 10.1016/j.marpolbul.2019.03.022. Epub 2019 Mar 27. PMID: 31232294.
8. Best Available Techniques (BAT) Reference Document for Waste Treatment, European IPPC Bureau, 2018, Retrieved from: https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/JRC113018_WT_Bref.pdf last accessed on 22 April 2021.
9. Bhatnagar VK, Patel JS, Varya MR, Venkaiah K, Shah MP, Kashyap SK (1992) Levels of organochlorine insecticides in human blood from Ahmedabad (rural), India. Bull Environ Contam Toxicol 48:302
10. Bhatnagar, V.K., Kashyap, R., Zaidi, S.S.A., Kulkarni, P.K. and Saiyed, H.N., 2004. Levels of DDT, HCH, and HCB residues in human blood in Ahmedabad, India. *Bulletin of environmental contamination and toxicology*, *72*(2), pp.261-265.
11. Brumovský, M., 2017. Emerging contaminants in marine waters 146.
12. Brun, G.L., MacDonald, R.M., Verge, J., Aube, J., 2008. Long-term atmospheric deposition of current-use and banned pesticides in Atlantic Canada; 1980-2000. Chemosphere 71, 314–327. https://doi.org/10.1016/j.chemosphere.2007.09.003
13. BSEF. Bromine Science and Environmental Forum. About Hexabromocyclododecane (HBCD). 2010. http://www.bsef.com/our-substances/hbcd/about-hbcd/ (accessed June 2010).
14. By Swati Singh Sambyal, Richa Agarwal , Down To Earth, Burn it all-That is NITI Aayog's solution to India's solid waste management woes", 2017. Accessed at https://www.downtoearth.org.in/news/waste/burn-it-all-58827
15. Cabinet approves Ratification of seven Persistent Organic Pollutants listed under Stockholm Convention and delegate its powers for future ratifications for streamlining the procedure.https://pib.gov.in/PressReleasePage.aspx?PRID=1662335
16. Canadian Council of Ministers of the Environment: Quality guidelines. Retrieved from: https://www.ccme.

ca/en/resources/canadian_environmental_quality_guidelines/ last accessed on April 15, 2021.

17. Carbery, M., O'Connor, W., & Thavanani, P., Trophic transfer of microplastics in the marine food web and implications on human health (Environment International 2018)
18. Chaemfa C, Xu Y, Li J, Chakraborty P, Hussain Syed J, Naseem Malik R, Wang Y, Tian C, Zhang G, Jones KC. Screening of atmospheric short- and medium-chain chlorinated paraffins in India and Pakistan using polyurethane foam based passive air sampler. Environ Sci Technol. 2014 May 6;48(9):4799-808. doi: 10.1021/es405186m. Epub 2014 Apr 14. PMID: 24666432.
19. Chakraborty P, Sampath S, Mukhopadhyay M, Selvaraj S, Bharat GK, Nizzetto L. Baseline investigation on plasticizers, bisphenol A, polycyclic aromatic hydrocarbons and heavy metals in the surface soil of the informal electronic waste recycling workshops and nearby open dumpsites in Indian metropolitan cities. Environ Pollut. 2019 May;248:1036-1045. doi: 10.1016/j.envpol.2018.11.010. Epub 2018 Nov 5. PMID: 31091636.
20. Chakraborty P, Selvaraj S, Nakamura M, Prithiviraj B, Cincinelli A, Bang JJ. PCBs and PCDD/Fs in soil from informal e-waste recycling sites and open dumpsites in India: Levels, congener profiles and health risk assessment. Sci Total Environ. 2018 Apr 15;621:930-938. doi: 10.1016/j.scitotenv.2017.11.083. Epub 2017 Dec 18. PMID: 29223911.
21. Chakraborty P, Zhang G, Cheng H, Balasubramanian P, Li J, Jones KC. Passive air sampling of polybrominated diphenyl ethers in New Delhi, Kolkata, Mumbai and Chennai: Levels, homologous profiling and source apportionment. Environ Pollut. 2017 Dec;231(Pt 1):1181-1187. doi: 10.1016/j.envpol.2017.08.044. Epub 2017 Sep 12. PMID: 28911793.
22. Chakraborty P, Zhang G, Li J, et al (2010) Selected organochlorine pesticides in the atmosphere of major Indian Cities: Levels, regional versus local variations, and sources. Environ Sci Technol 44:8038–8043. https://doi.org/10.1021/es102029t
23. Chakraborty, P., Khuman, S.N., Selvaraj, S., Sampath, S., Devi, N.L., Bang, J.J., Katsoyiannis, A., 2016. Polychlorinated biphenyls and organochlorine pesticides in River Brahmaputra from the outer Himalayan Range and River Hooghly emptying into the Bay of Bengal: Occurrence, sources and ecotoxicological risk assessment. Environ. Pollut. 219, 998–1006. https://doi.org/https://doi.org/10.1016/j.envpol.2016.06.067
24. Chakraborty, P., Zhang, G., Li, J., Sampathkumar, P., Balasubramanian, T., Kathiresan, K., Takahashi, S., Subramanian, A., Tanabe, S., Jones, K.C., 2019. Seasonal variation of atmospheric organochlorine pesticides and polybrominated diphenyl ethers in Parangipettai, Tamil Nadu, India: Implication for atmospheric transport. Sci. Total Environ. 649, 1653–1660. https://doi.org/10.1016/j.scitotenv.2018.07.414
25. Chakraborty, P., Zhang, G., Li, J., Sivakumar, A., Jones, K.C., 2015. Occurrence and sources of selected organochlorine pesticides in the soil of seven major Indian cities: Assessment of air–soil exchange. Environ. Pollut. 204, 74–80. https://doi.org/https://doi.org/10.1016/j.envpol.2015.04.006
26. Chemical requirements in the POPs Regulation, Swedish Chemical Agency, September 2017; Retrieved from: https://www.kemi.se/en/global/faktablad/facts-chemical-requirements-in-the-pops-regulation.pdf last accessed on 22 April 2021
27. Children's Health and the Environment. WHO Training Package for the Health Sector World Health Organization (WHO), July 2008; Retrieved from: https://www.who.int/ceh/capacity/POPs.pdf last accessed on April 5, 2021.
28. Cole M, Lindeque P, Halsband C, Galloway TS. Microplastics as contaminants in the marine environment: a review. Mar Pollut Bull. 2011 Dec;62(12):2588-97. doi: 10.1016/j.marpolbul.2011.09.025. Epub 2011 Oct 14. PMID: 22001295.
29. CPCB (1996). Inventorisation of hazardous waste generation in five districts (Ahmedabad, Vadodara, Bharuch, Surat and Valsad) of Gujarat. Central Pollution Control Board (Ministry of Environment & Forests, Government of India). ISBN 8186396632
30. Danish EPA. 1999. Brominated flame retardants. Substance flow analysis and assessment of alternatives.
31. Daso, Adegbenro Peter & Fatoki, Olalekan & Odendaal, James. (2015). Evaluation of polybrominated diphenyl ethers (PBDEs) and 2,2',4,4',5,5'- hexabromobiphenyl (BB-153) burdens of sediment samples from the Diep and Kuils Rivers, Cape Town, South Africa. International Journal of Sediment Research. 31. 10.1016/j.ijsrc.2013.10.001.
32. DDT Losing Grounds in India: Alternatives Imminent, Toxics Link. Factsheet No. 38, May 2011

33. Dhananjayan V, Muralidharan S (2010) Levels of organochlorine pesticide residues in blood plasma of various species of birds from India. Bull Environ Contam Toxicol 85:129–136. https://doi.org/10.1007/s00128-010-0045-6
34. Dhananjayan, V. and Muralidharan, S., 2013. Levels of polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and organochlorine pesticides in various tissues of white-backed vulture in India. *BioMed research international*, *2013*.
35. Dioxin (PCDDs) and Furan (PCDFs) - Critical Persistent Organic Pollutants (POPs). Central Pollution Control Board (CPCB). 2003. Retrieved from: http://www.cpcbenvis.nic.in/cpcb_newsletter/Dioxin.pdf last accessed on April 15, 2021.
36. Dioxin research, CSIR – National Institute for Interdisciplinary Science and Technology (NIIST), n.d., Retrieved from: https://www.niist.res.in/english/research-areas/process-engineering-and-environmental-technology/dioxin-research/highlights.html last accessed on 22 April 2021
37. Draft Guidance Document on Best Available Techniques to control emissions of persistent Organic Pollutants from major stationary sources, United Nations Economic Commission for Europe (UNECE), October 2009, Retrieved from: https://www.unece.org/fileadmin/DAM/env/documents/2009/EB/eb/ece.eb.air.2009.14.e.pdf last accessed on 22 April 2021
38. Draft guidance on best available techniques and best environmental practices for the production and use of hexabromocyclododecane listed with specific exemptions under the Stockholm Convention, UNEP, January 2017, Retrieved from: http://chm.pops.int/Implementation/NationalImplementationPlans/GuidanceArchive/GuidanceonBATBEPforHBCD/tabid/5526/Default.aspx last accessed on 22 April 2021
39. Draft Risk Profile for Short Chained- chlorinated Paraffins, 4th Meeting of the Persistent Organic Pollutants Review Committee (POPRC-4). 2008
40. Dua VK, Kumari R, Johri RK, Ojha VP, Shukla RP, Sharma VP. Organochlorine insecticide residues in water from five lakes of Nainital (U. P.), India. Bull Environ Contam Toxicol. 1998 Feb;60(2):209-15. doi: 10.1007/s001289900612. PMID: 9470980.
41. Dubey, M. and Ujjania, N.C., 2013. Water quality and pollution status of Tapi river, Gujarat, India. *International Journal of Pure and Applied Zoology*, *1*(3), pp.261-266.
42. Fang, Yanyan & Nie, Zhiqiang & Die, Qingqi & Tian, Yajun & Liu, Feng & He, Jie & Huang, Qifei. (2017). Organochlorine pesticides in soil, air, and vegetation at and around a contaminated site in southwestern China: Concentration, transmission, and risk evaluation. Chemosphere. 178. 10.1016/j.chemosphere.2017.02.151.
43. García-Flor, N., Dachs, J., Bayona, J.M., Albaigés, J., 2009. Surface waters are a source of polychlorinated biphenyls to the coastal atmosphere of the North-Western Mediterranean Sea. Chemosphere 75, 1144–1152. https://doi.org/10.1016/j.chemosphere.2009.02.062
44. Gaur, S., 2018. An updated review on quantitative and qualitative analysis of water pollution in west flowing Tapi River of Gujarat, India. In *Environmental Pollution* (pp. 525-547). Springer, Singapore.
45. Gevao, Bondi & Beg, Mirza & Al-Ghadban, Abdul Nabi & Al-Omair, Ali & Murad, Helaleh & Zafar, Jamal. (2006). Spatial distribution of polybrominated diphenyl ethers in coastal marine sediments receiving industrial and municipal effluents in Kuwait. Chemosphere. 62. 1078-86. 10.1016/j.chemosphere.2005.05.030.
46. Gewurtz SB, Gandhi N, Drouillard KG, Kolic T, MacPherson K, Reiner EJ, Bhavsar SP. Levels, patterns, trends and significance of polychlorinated naphthalenes (PCNs) in Great Lakes fish. Sci Total Environ. 2018 May 15;624:499-508. doi: 10.1016/j.scitotenv.2017.11.332. Epub 2017 Dec 27. PMID: 29268222.
47. Goldman, G., M. Fernandes, M. Holland, T. Tugran, A. Nordin, C. Schoumacher and A. McNeil, 2019. The Cosy of Inaction: A socio-economic analysis of environmental and health impacts linked to exposure to PFAS. Copenhagen: Nordic Council of Ministers.
48. GPCB Report. 2013. Waste? A Resource at Wrong Place Co-processing Initiatives of Gujarat. Gujarat Pollution Control Board (GPCB).
49. Gray, J.S., 2002. Biomagnification in marine systems: the perspective of an ecologist. Marine Pollution Bulletin 45, 46–52. https://doi.org/10.1016/S0025-326X(01)00323-X
50. Guidelines for Drinking Water Quality – Third Edition Incorporating the First and second Addenda. Volume I. Recommendations. World Health Organization (WHO). 2008. Retrieved from: https://www.who.int/water_sanitation_health/dwq/fulltext.pdf last accessed on April 15, 2021.

51. Gujarat Ecology Commission - Environmental Information System (GEC-ENVIS). 2004. Status of environmental pollution in Gujarat. Retrieved from: http://www.gujenvis.nic.in/PDF/soe-industrial.pdf last accessed on April 15, 2021.
52. Hale RC, La Guardia MJ, Harvey E, Mainor TM. Potential role of fire retardant-treated polyurethane foam as a source of brominated diphenyl ethers to the US environment. Chemosphere. 2002 Feb;46(5):729-35. doi: 10.1016/s0045-6535(01)00237-5. PMID: 11999796.
53. Hamsagayathri, P., Rajakumari, K., Ramya, P., & Ali, K. S. (2020). Convergence of IoT, AI, and Blockchain. In *Blockchain, Big Data and Machine Learning* (pp. 291–313). CRC Press. https://doi.org/10.1201/9780429352546-12
54. Hashmi, T.A., Qureshi, R., Tipre, D. and Menon, S., 2020. Investigation of pesticide residues in water, sediments and fish samples from Tapi River, India as a case study and its forensic significance. *Environmental Forensics*, *21*(1), pp.1-10.
55. Herrera-Herrera A V., Asensio-Ramos M, Hernández-Borges J, Rodríguez-Delgado MÁ (2010) Dispersive liquid-liquid microextraction for determination of organic analytes. TrAC - Trends Anal. Chem. 29:728–751
56. History of the negotiations of the Rotterdam Convention; Retrieved from: http://www.pic.int/TheConvention/Overview/History/Overview/tabid/1360/language/en-US/Default.aspx last accessed on 22 April 2021
57. Horton AA, Walton A, Spurgeon DJ, Lahive E, Svendsen C. Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. Sci Total Environ. 2017 May 15;586:127-141. doi: 10.1016/j.scitotenv.2017.01.190. Epub 2017 Feb 4. PMID: 28169032.
58. Human Health Implications of POPs. PoPs Toolkit - Health Implications. n.d. Retrieved from: http://www.popstoolkit.com/about/healthimplications.aspx last accessed on April 2021
59. Important Projects Undertaken. National Reference Trace Organics Laboratory (NRTOL), Central Pollution Control Board (CPCB). Retrieved from: https://www.cpcb.nic.in/uploads/Laboratory/Trace-Organic/NRTOL-Important_Projects_Undertaken.pdf last accessed on April 15, 2021.
60. International Conventions; Retrieved from: https://ec.europa.eu/environment/chemicals/international_conventions/index_en.htm last accessed on 22 April 2021
61. Jacobsen J. B. and N. Hanley, 2009. Are There Income Effects on Global Willingness to Pay for Biodiversity Conservation? Environmental and Resource Economics, Volume 43 (2): 137–160.
62. Jani, J.P., Patel, J.S., Shah, M.P., Gupta, S.K. and Kashyap, S.K., 1988. Levels of organochlorine pesticides in human milk in Ahmedabad, India. *International archives of occupational and environmental health*, *60*(2), pp.111-113.
63. Joint Meeting on Pesticide Residues (JMPR). World Health Organization (WHO). Retrieved from: https://www.who.int/foodsafety/areas_work/chemical-risks/jmpr/en/ last accessed on April 15, 2021.
64. Joint Report on Monitoring of Common Effluent Treatment Plant (CETP) Vapi Industrial Area, Gujarat. Central Pollution Control Board (CPCB). 2020. (Based on information/data of GPCB, RO, Vapi & M/s VGEL, Vapi –April 2020-June2020). Retrieved from: https://greentribunal.gov.in/sites/default/files/news_updates/Sixth%20Joint%20Report%20BY%20CPCB%20on%20Monitoring%20of%20CETP%20in%20OA%20No.%2095%20of%202018%20(Aryavart%20Foundation%20Vs.%20Vapi%20Green%20Enviro%20Ltd.%20&%20Ors.).pdf last accessed on April 9, 2021.
65. Jönsson, A., Gustafsson, Ö., Axelman, J., Sundberg, H., 2003. Global Accounting of PCBs in the Continental Shelf Sediments. Environmental Science & Technology 37, 245–255. https://doi.org/10.1021/es0201404
66. Juang D-F, Lee C-H, Chen W-C, Yuan C-S (2010) Do the VOCs that evaporate from a heavily polluted river threaten the health of riparian residents? Sci. Tot. Env. 408(20), 4524–4531.
67. Jurado, E., Dachs, J., 2008. Seasonality in the “grasshopping” and atmospheric residence times of persistent organic pollutants over the oceans. Geophysical Research Letters 35, L17805. https://doi.org/10.1029/2008GL034698
68. Jurado, E., Zaldívar, J.-M., Marinov, D., Dachs, J., 2007. Fate of persistent organic pollutants in the water column: Does turbulent mixing matter? Marine Pollution Bulletin 54, 441–451. https://doi.org/10.1016/j.marpolbul.2006.11.028
69. Kannan K, Koistinen J, Beckmen K, et al (2001) Accumulation of perfluorooctane sulfonate in marine mammals. Environ Sci Technol 35:1593–1598. https://doi.org/10.1021/es001873w

70. Kathuria, V. (2001). Pollution: Prevention vs Control: Is EOP Treatment the Solution? Economic and Political Weekly, 36(29), 2745-2748. Retrieved April 16, 2021, from http://www.jstor.org/stable/4410880
71. Kramm, Johanna and V€olker, Carolin. 2018. Understanding the Risks of Microplastics: A Social-Ecological Risk Perspective. Freshwater Microplastics, Hdb Env Chem 58, DOI 10.1007/978-3-319-61615-5_11
72. Labunska, I., Stephenson, A., Brigden, K., Santillo, D., Stringer, R., Johnston, P.A. and Ashton, J.M., 1999. Organic and heavy metal contaminants in samples taken at three industrial estates in Gujarat, India. *Greenpeace Research Laboratories Exeter*.
73. Learn about Dioxin. United States Environmental Protection Agency (USEPA). Retrieved from: https://www.epa.gov/dioxin/learn-about-dioxin last accessed on April 15, 2021.
74. Lecloux, A. 2004. Hexachlorobutadiene – Sources, environmental fate and risk characterisation. Science dossier. EuroChlor 17. 48 p. www.eurochlor.org
75. Leisewitz A, Kruse H, Schramm E (2000). German Federal Ministry of the Environment, Nature Conservation, and Nuclear Safety, Substituting Environmentally relevant flame retardants: Assessment Fundamentals, Research Report 204 08 642 or 207 44 542, 2000.
76. Li MT, Hao LL, Sheng LX, Xu JB (2008) Identification and degradation characterization of hexachlorobutadiene degrading strain Serratia marcescens HL1. Bioresour Technol. 99, 6878-6884
77. Li, Y., Lin, T., Hu, L., Feng, J., Guo, Z., 2016. Time trends of polybrominated diphenyl ethers in East China Seas: Response to the booming of PBDE pollution industry in China. Environ. Int. 92–93, 507–514. https://doi.org/10.1016/j.envint.2016.04.033
78. Lin, T., Guo, Z., Li, Y., Nizzetto, L., Ma, C., Chen, Y., 2015. Air-Seawater Exchange of Organochlorine Pesticides along the Sediment Plume of a Large Contaminated River. Environ. Sci. Technol. 49, 5354–5362. https://doi.org/10.1021/es505084j
79. Lin, T., Nizzetto, L., Guo, Z., Li, Y., Li, J., Zhang, G., 2016. DDTs and HCHs in sediment cores from the coastal East China Sea. Sci. Total Environ. 539, 388–394. https://doi.org/10.1016/j.scitotenv2015.09.010
80. Lohmann R, Muir D, Zeng EY, et al (2017) Aquatic Global Passive Sampling (AQUA-GAPS) Revisited: First Steps toward a Network of Networks for Monitoring Organic Contaminants in the Aquatic Environment. Environ Sci Technol 51:1060–1067. https://doi.org/10.1021/acs.est.6b05159
81. Lohmann, R., Breivik, K., Dachs, J., Muir, D., 2007. Global fate of POPs: Current and future research directions. Environmental Pollution 150, 150–165. https://doi.org/10.1016/j.envpol.2007.06.051
82. Malik, A.; Ojha, P.; and Singh, K.P. (2009). Levels and distribution of persistent organochlorine pesticide residues in water and sediments of Gomti River (India)—a tributary of the Ganges River. Environ. Monit. Assess. 148, 421–435, https://doi.org/10.1007/s10661-008-0172-2.
83. Mukhopadhyay, Moitraiyee & Sampath, Srimurali & Muñoz-Arnanz, Juan & Jiménez, Begoña & Chakraborty, Paromita. (2020). Plasticizers and bisphenol A in Adyar and Cooum riverine sediments, India: occurrences, sources and risk assessment. Environmental Geochemistry and Health. 42. 10.1007/s10653-020-00516-3.
84. Nair S (2018) Environment Ministry notifies rules to regulate the use of POPs. https://www.jagranjosh.com/current-affairs/environment-ministry-notifies-rules-to-regulate-the-use-of-pops-1520846915-1. Accessed 21 Apr 2020
85. National Implementation Plan (NIP) on Elimination and Reduction of Persistent Organic Pollutants in Indonesia, The Republic of Indonesia. UNEP-POP-NIP-Indonesia July 2008
86. National Implementation Plan (NIP), Stockholm Convention, Brazil. UNEP-POPS-NIP-Brazil. 2015
87. National Implementation Plan, Government of India. Stockholm Convention on Persistent Organic Pollutants. April 2011. Retrieved from: http://chm.pops.int/Implementation/NationalImplementationPlans/NIPTransmission/tabid/253/ctl/Download/mid/13657/Default.aspx?id=80&ObjID=11745 last accessed on April 9, 2021
88. Navrud S., 2017. Possibilities and challenges in transfer and generalisation of monetary estimates for environmental and health benefits of regulating chemicals. OECD Environment Working Papers No. 119. Paris: OECD.
89. NGO Shipbreaking Platform. N.d. India. Retrieved from: https://shipbreakingplatform.org/our-work/the-problem/india/#:☐:text=The%20shipbreaking%20yards%20in%20Alang,the%20world's%20largest%20shipbreaking%20site last accessed on April 15, 2021.
90. NIUA Editorial Team. (2017). Editorial. *Swachh Bharat: A Monthly Newsletter*, *3*(1). http://

swachhbharaturban.gov.in/Auth/dsdocumentsfile.aspx?DOCTYPE=922&DOCID=61

91. Nizzetto, L., Butterfield, D., Futter, M., Lin, Y., Allan, I., Larssen, T., 2016. Assessment of contaminant fate in catchments using a novel integrated hydrobiogeochemical-multimedia fate model. Sci. Total Environ. 544, 553–563. https://doi.org/10.1016/j.scitotenv.2015.11.087
92. Nizzetto, L., Macleod, M., Borga, K., Cabrerizo, A., Dachs, J., Di Guardo, A., Ghirardello, D., Hansen, K.M., Jarvis, A., Lindroth, A., Ludwig, B., Monteith, D., Perlinger, J.A., Scheringer, M., Schwendenmann, L., Semple, K.T., Wick, L.Y., Zhang, G., Jones, K.C., 2010. Past, Present, and Future Controls on Levels of Persistent Organic Pollutants in the Global Environment. Environ. Sci. Technol. 44, 6526–6531. https://doi.org/10.1021/es100178f
93. Octabromodiphenyl ether: Risk Reduction Strategy and Analysis of Advantages and Drawbacks. Final report. Report prepared for Department for Environment, Food and Rural Affairs. Risk and Policy Analysts Limited, June 2002.
94. Ogata, Y., Takada, H., Mizukawa, K., Hirai, H., Iwasa, S., 2009. International pellet watch: global monitoring of persistent organic pollutants (POPs) in coastal waters 1 initial phase data on PCBs DDTs and HCHs. Mar. Pollut. Bull. 58, 1437–1446
95. Oosterhuis, F. and R. Brouwer, 2015. Benchmark development for the proportionality assessment of PBT and vPvB substances. Report R-15/11. IVM Institute for Environmental Studies.
96. Oosterhuis, F., R. Brouwer, M. Janssen, J. Verhoeven and C. Luttikhuizen, 2017. Towards a Proportionality Assessment of Risk Reduction Measures Aimed at Restricting the Use of Persistent and Bioaccumulative Substances. Integrated Environmental Assessment and Management 13 (6): 1100 – 1112.
97. OSPAR Commission, 2001: Polychlorinated Biphenyls (PCBs). Retrieved from: https://www.ospar.org/documents?v=6918 last accessed on April 27, 202
98. Overview of Rotterdam Convention; Retrieved from: http://www.pic.int/TheConvention/Overview/tabid/1044/language/en-US/Default.aspx last accessed on 22 April 2021
99. Overview of the Stockholm Convention. Retrieved from: http://www.pops.int/TheConvention/Overview/tabid/3351/Default.aspx last accessed on 22 April 2021
100. Persistent organic pollutants – a new family of substances for ECHA, European Chemical Agency (ECHA), November 2018, Retrieved from: https://newsletter.echa.europa.eu/home/-/newsletter/entry/persistent-organic-pollutants-a-new-family-of-substances-for-echa last accessed on 22 April 2021
101. Persistent Organic Pollutants (POPs) in India. Toxics Link, 2018. Retrieved from: http://toxicslink.org/docs/country%20situation%20report_new%20size.pdf last accessed on April 9, 2021
102. Piehl, S., Leibner, A., Löder, M., Dris, R., Bogner, C., & Laforsch, C. (2018). Identification and quantification of macro- and microplastics on an agricultural farmland. Scientific reports, 8(1), 17950. https://doi.org/10.1038/s41598-018-36172-y
103. Planning Commission. (2014). Report of the Task Force on Waste to Energy (Volume I) (In the context of Integrated MSW Management) Planning Commission Submission Certificate of the Report of the Task Force. i Preface ii Acknowledgements v. http://swachhbharaturban.gov.in/writereaddata/Task_force_report_on_WTE.pdf
104. Plastic & Health: The Hidden Costs of a Plastic Planet; Center for International Environmental Law (CIEL); February 2019
105. POPs: Contaminated site investigation and management Toolkit, United Nations Industrial Development Organization (UNIDO), n.d., Retrieved from: http://chm.pops.int/Implementation/BATandBEP/AdditionalResources/tabid/1493/Default.aspx last accessed on 22 April 2021
106. POPs; Retrieved from: https://ec.europa.eu/environment/archives/pops/index_en.htm last accessed on 22 April 2021
107. Pozo K, Harner T, Lee SC, et al (2009) Seasonally resolved concentrations of persistent organic pollutants in the global atmosphere from the first year of the GAPS Study. Environ Sci Technol 43:796–803. https://doi.org/10.1021/es802106a
108. REACH Annex XIV: REACH Authorization List 2020; Retrieved from: https://www.chemsafetypro.com/Topics/EU/REACH_annex_xiv_REACH_authorization_list.html last accessed on 22 April 2021
109. REACH Annex XVII: REACH Restricted Substance List 2020; Retrieved from: https://www.chemsafetypro.com/Topics/EU/REACH_annex_xvii_REACH_restricted_substance_list.html last accessed on 22 April 2021

110. Regulation 2019/1021 of the European Parliament and of the Council of 20 June 2019 on persistent organic pollutants. European Union (EU) 2019. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R1021&from=EN last accessed on 22 April 2021

111. Ritchie, Hannah and Roser, Max. (2020) - "Plastic Pollution". *Published online at OurWorldInData.org.* Retrieved from: 'https://ourworldindata.org/plastic-pollution' [Online Resource]

112. RPA (Risk & Policy Analysis), 2019. Socio-Economic Assessment of PFHxS and PFHxS-related Substances. Report for the Norwegian Environment Agency, May 2019, Loddon, Norfolk, UK.

113. Ruzzin J. Public health concern behind the exposure to persistent organic pollutants and the risk of metabolic diseases. *BMC Public Health*. 2012;12:298. Published 2012 Apr 20. doi:10.1186/1471-2458-12-298

114. SAICM overview, Retrieved from: http://www.saicm.org/About/SAICMOverview/tabid/5522/language/en-US/Default.aspx last accessed on 22 April 2021

115. Sakai S, Urano S, Takatsuki H. Leaching behavior of persistent organic pollutants (POPs) in shredder residues. Chemosphere. 1998 Oct-Nov;37(9-12):2047-54. doi: 10.1016/s0045-6535(98)00268-9. PMID: 9828329.

116. Salihovic S, Mattioli L, Lindström G, et al (2012) A rapid method for screening of the Stockholm Convention POPs in small amounts of human plasma using SPE and HRGC/HRMS. Chemosphere 86:747–753. https://doi.org/10.1016/j.chemosphere.2011.11.006

117. Sanka, O., Kalina, J., Lin, Y., Deutscher, J., Futter, M., Butterfield, D., Melymuk, L., Brabec, K., Nizzetto, L., 2018. Estimation of p,p'-DDT degradation in soil by modeling and constraining hydrological and biogeochemical controls. Environ. Pollut. 239, 179–188. https://doi.org/10.1016/j.envpol.2018.04.022

118. Schecter A (1994) Exposure Assessment. In: Dioxins and Health. Springer US, Boston, MA, pp 449–485

119. Scherer, Christian & Weber, Annkatrin & Lambert, Scott & Wagner, Martin. (2018). Interactions of Microplastics with Freshwater Biota. 10.1007/978-3-319-61615-5_8.

120. Second Advisory Board & Expert Group Meeting of Special Directorate on Chemicals and Waste with special Focus on POPs supported by UNEP, SC Regional Centre on POPs for Asia Region, CSIR-National Environmental Engineering Research Institute (NEERI), January 2020, Retrieved from: http://neeriathome.neeri.res.in/scrc/images/workplan/1583314362Second%20Advisory%20and%20Expert%20group%20meeting%207-8%20jan.pdf last accessed on 22 April 2021

121. Sharma BM, Bharat GK, Tayal S, Nizzetto L, Larssen T. The legal framework to manage chemical pollution in India and the lesson from the Persistent Organic Pollutants (POPs). *Sci Total Environ*. 2014;490:733-747. doi:10.1016/j.scitotenv.2014.05.043

122. Sharma, B. M., Bharat, G.K., Tayal, S., Larssen, T., Becanova, J., Karaskov, P., Whitehead, P.G., Futter, M. N., Butterfield, D., Nizzetto, L. (2016) Perfluoroalkyl substances (PFAS) in river and ground/drinking water of the Ganges River basin: Emissions and implications for human exposure. Environmental Pollution 208 (2016) 704-713.

123. Shyam Divan, Armin Rosencranz, Environmental law and policy in India, Oxford University Press, 2001.

124. Sobek, A., Gustafsson, Ö., Hajdu, S., Larsson, U., 2004. Particle–Water Partitioning of PCBs in the Photic Zone: A 25-Month Study in the Open Baltic Sea. Environmental Science & Technology 38, 1375–1382. https://doi.org/10.1021/es034447u

125. Someya M, Ohtake M, Kunisue T, Subramanian A, Takahashi S, Chakraborty P, Ramachandran R, Tanabe S. (2010). Persistent organic pollutants in breast milk of mothers residing around an open dumping site in Kolkata, India: specific dioxin-like PCB levels and fish as a potential source. Environ Int. 2010 Jan;36(1):27-35. doi: 10.1016/j.envint.2009.09.003. Epub 2009 Oct 25. PMID: 19854513.

126. Sources of Maps: Quick bird image; Google Earth Pro; ARCGIS Tool (version 9.3) with standard reference topographical sheets acquired from Survey of India.

127. Spinnel E, Danielsson C, Haglund P (2008) Rapid and cost-effective analysis of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans in soil, fly ash and sediment certified reference materials using pressurized liquid extraction with an integrated carbon trap. Anal Bioanal Chem 390:411–417. https://doi.org/10.1007/s00216-007-1696-y

128. Stockholm Convention on Persistent Organic Pollutants (SC-POPs) to enter into force 17 May 2004. United Nations (UN). 2004. Retrieved from: https://www.un.org/press/en/2004/unep204.doc.htm last accessed on April 5, 2021.

129. Stockholm Convention, CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), India. Accessed at http://chm.pops.int/?tabid=806

130. Subedi B, Usenko S (2012) Enhanced pressurized liquid extraction technique capable of analyzing polychlorodibenzo-p-dioxins, polychlorodibenzofurans, and polychlorobiphenyls in fish tissue. J Chromatogr A 1238:30–37. https://doi.org/10.1016/j.chroma.2012.03.037

131. Svarcova A, Lankova D, Gramblicka T, Stupak M, Hajslova J, Pulkrabova J. Integration of five groups of POPs into one multi-analyte method for human blood serum analysis: An innovative approach within biomonitoring studies. Sci Total Environ. 2019 Jun 1;667:701-709. doi: 10.1016/j.scitotenv.2019.02.336. Epub 2019 Feb 22. PMID: 30849610.

132. Tang, Z. R., Xu, X. L., Deng, S. L., Lian, Z. X., & Yu, K. (2020). Oestrogenic Endocrine Disruptors in the Placenta and the Fetus. International journal of molecular sciences, 21(4), 1519. https://doi.org/10.3390/ijms21041519

133. Thacker N, Sheikh J, Tamane SM, Bhanarkar A, Majumdar D, Singh K, Chavhan C, Trivedi J. Emissions of polychlorinated dibenzo-p-dioxins (PCDDs), dibenzofurans (PCDFs), and dioxin-like polychlorinated biphenyls (PCBs) to air from waste incinerators and high thermal processes in India. Environ Monit Assess. 2013 Jan;185(1):425-9. doi: 10.1007/s10661-012-2564-6. Epub 2012 Mar 2. PMID: 22382379.

134. The Basel Convention at A Glance; Basel Convention, n.d. Retrieved from: http://www.basel.int/Portals/4/Basel%20Convention/docs/convention/bc_glance.pdf last accessed on April 23, 2021.

135. The National Implementation Plan (NIP), Stockholm Convention on Persistent Organic Pollutants; Government of India

136. The People's Republic of China National Implementation Plan (NIP) for the Stockholm Convention on Persistent Organic Pollutants, UNEP-POPS-NIP-China. April 2007.

137. The People's Republic of China National Implementation Plan (NIP) for the Stockholm Convention on Persistent Organic Pollutants (Enlarged Edition) (COP-6). UNEP-POPS-NIP-China-COP6. n.d.

138. Toxicant and Disease Database, Collaborative on Health and Environment (CHE). 2019. Retrieved from: https://www.healthandenvironment.org/our-work/toxicant-and-disease-database/ last accessed on April 5, 2021.

139. Toxicological Profile for Polybrominated Diphenyl Ethers (PBDEs). Agency for Toxic Substances and Disease Registry: ATSDR. 2017. Retrieved from: https://www.atsdr.cdc.gov/toxprofiles/tp207-c8.pdf last accessed on April 15, 2021.

140. Tue, N. M., Sudaryanto, A., Tu, B. M., Isobe, T., Takahashi, S., Pham H. V. & Tanabe, S. 2010. Accumulation of polychlorinated biphenyls and brominated flame retardants in breast milk from women living in Vietnamese e-waste recycling sites. Science of The Total Environment, 408, 2155-2162.

141. TUVSUD Newsletter, 2019; Retrieved from: https://www.tuvsud.com/en/e-ssentials-newsletter/consumer-products-and-retail-essentials/e-ssentials-10-2019/eu-pops-regulation-recast-is-now-published last accessed on 22 April 2021

142. Ueno, D., Kajiwara, N., Tanaka, H., Subramanian, A., Fillmann, G., Lam, P.K.S., Zheng, G.J., Muchitar, M., Razak, H., Prudente, M., Chung, K. and Tanabe, S. 2004. Global Pollution Monitoring of Polybrominated Diphenyl Ethers Using Skipjack Tuna as a Bioindicator. Environ. Sci. Technol. 38: 2312-2316.

143. Understanding REACH; Retrieved from: https://echa.europa.eu/regulations/reach/understanding-reach last accessed on 22 April 2021

144. UNEP Regional Plan on the elimination in the framework of the implementation of Article 15 of the LBS Protocol, 1996. UNEP/MAP, 10/02/**2012**.

145. UNEP. 2009. Stockholm Convention on Persistent Organic Pollutants. Geneva

146. UNEP. 2017. The New POPs under the Stockholm Convention. Geneva

147. Van der Honing M (2007) Exploration of management options for Hexachlorobutadiene (HCBD) Paper for the 6th meeting of the UNECE CLRTAP Task Force on Persistent Organic Pollutants, Vienna, 4-6 June 2007. SenterNovem, The Netherlands, 2007.

148. Verbrugge, L.A., Kahn, L. & Morton, J.M. Pentachlorophenol, polychlorinated dibenzo-p-dioxins and polychlorinated dibenzo furans in surface soil surrounding pentachlorophenol-treated utility poles on the Kenai National Wildlife Refuge, Alaska USA. *Environ Sci Pollut Res* **25,** 19187–19195 (2018). https://doi.org/10.1007/s11356-018-2269-7

149. Wang Q, Zhao Z, Ruan Y, Li J, Sun H, Zhang G. Occurrence and distribution of perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS)

in natural forest soils: A nationwide study in China. Sci Total Environ. 2018 Dec 15;645:596-602. doi: 10.1016/j.scitotenv.2018.07.151. Epub 2018 Jul 18. PMID: 30029134.

150. Waring RH, Harris RM, Mitchell SC. Plastic contamination of the food chain: A threat to human health? Maturitas. 2018 Sep;115:64-68. doi: 10.1016/j.maturitas.2018.06.010. Epub 2018 Jun 20. PMID: 30049349

151. WCC 2002: Euro Chlor Risk Assessment for the Marine Environment OSPARCOM Region - North Sea: Hexachlorobutadiene.

152. WHO guidelines for drinking water. 2011. World Health Organization (WHO).

153. WHO guidelines for indoor air quality: selected pollutants. 2010. World Health Organization (WHO).

154. Xu W, Wang X, Cai Z (2013) Analytical chemistry of the persistent organic pollutants identified in the Stockholm Convention: A review. Anal. Chim. Acta 790:1–13

155. Xu Y, Li J, Chakraborty P, Syed JH, Malik RN, Wang Y, Tian C, Luo C, Zhang G, Jones KC. Atmospheric polychlorinated naphthalenes (PCNs) in India and Pakistan. Sci Total Environ. 2014 Jan 1;466-467:1030-6. doi: 10.1016/j.scitotenv.2013.07.078. Epub 2013 Aug 28. PMID: 23988747.

156. Yang F, Jin S, Meng D, Xu Y (2010) Solid phase extraction with pyrenebutyric acid-bonded silica for analysis of polychlorinated biphenyls in sewage water by gas chromatography-mass spectrometry. Chemosphere 81:1000–1005. https://doi.org/10.1016/j.chemosphere.2010.09.016

157. Zhang H, Jiang L, Zhou X, et al (2018) Determination of hexachlorobutadiene, pentachlorobenzene, and hexachlorobenzene in waste incineration fly ash using ultrasonic extraction followed by column cleanup and GC-MS analysis. Anal Bioanal Chem 410:1893–1902.

158. Zhang X, Yang F, Luo C, Wen S, Zhang X, Xu Y. Bioaccumulative characteristics of hexabromocyclododecanes in freshwater species from an electronic waste recycling area in China. Chemosphere. 2009 Sep;76(11):1572-8. doi: 10.1016/j.chemosphere.2009.05.031. Epub 2009 Jul 18. PMID: 19616822.

159. Zhang, G., Chakraborty, P., Li, J., Sampathkumar, P., Balasubramanian, T., Kathiresan, K., Takahashi, S., Subramanian, A., Tanabe, S. and Jones, K.C., 2008. Passive atmospheric sampling of organochlorine pesticides, polychlorinated biphenyls, and polybrominated diphenyl ethers in urban, rural, and wetland sites along the coastal length of India. *Environmental science & technology*, *42*(22), pp.8218-8223.

160. Zhao A, Wang X, Ma M, et al (2012) Temperature-assisted ionic liquid dispersive liquid-liquid microextraction combined with high performance liquid chromatography for the determination of PCBs and PBDEs in water and urine samples. Microchim Acta 177:229–236. https://doi.org/10.1007/s00604-012-0776-7

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