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PLASTIC WASTE MANAGEMENT STRATEGY REPORT FOR GUJARAT

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

INOPOL

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New Delhi

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INOPOL (2022) Plastic Waste Management Strategy Report for Gujarat

Acknowledgements

The Plastic Waste Management Strategy Report for Gujarat 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)**, a research and consultancy organization working towards environmental friendly solutions in promoting green development across India; **The Energy and Resources Institute (TERI)**, a not-for-profit, multi-dimensional, policy research organization working in the fields of energy, environment, and sustainable development, and **Central Institute of Petrochemicals Engineering & Technology (CIPET)**, a premier academic institution working on developing plastics recycling technology and cost-effective recycled plastics. The research for the Plastic Waste Management Strategy Report for Gujarat 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 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 three 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 publication of the INOPOL project's Plastic Waste Management Strategy for Gujarat State, India. The Strategy document 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.

The close bilateral dialogue and transdisciplinary relationships developed as part of the INOPOL project will be key when we continue to explore the feasibility of establishing a new global agreement to combat plastic pollution. A robust scientific knowledge basis is pivotal when finding mutual grounds and developing effective measures on the multilateral arena. At the Embassy, we are delighted to read the extensive report, informed by research conducted under the INOPOL project, which is a repository of knowledge. The strategy document bridges important knowledge gaps on plastic 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.

Hans Jacob Frydenlund
Ambassador, The Royal Norwegian Embassy in New Delhi

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 the INOPOL project's Plastic Waste Management Strategy for Gujarat State, India, which provides a starting point to reduce plastic and chemical pollution in Gujarat State, India, the region and beyond. The strategy document provides important insights for the Indian policy environment, on pollution levels, existing monitoring practices, related health and environmental impacts, best practices and ways forward. This science-based knowledge forms the foundation of developing future actions 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, the Government of India and Gujarat State for excellent cooperation, and the entire project team for their great efforts.

Dr. Thorjørn Larssen
Deputy Managing Director, Norwegian Institute for Water Research

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List of ABBREVIATIONS AND ACRONYMS

ABS	Acrylonitrile Butadiene Styrene
AMC	Ambikapur Municipal Corporation
BAT	Best Available Technology
BBMP	Bruhat Bengaluru Mahanagara Palike
BEP	Best Environmental Practices
BO	Brand Owner
C&D	Construction and demolition
CETP	Common Effluent Treatment Plant
CII	Confederation of Indian Industry
CII-ITC CESD	CII-ITC Centre of Excellence for Sustainable Development
CIPET	Central Institute of Petrochemicals Engineering & Technology
CCIF	Coca Cola India Foundation
CCP	City Corporation of Panaji
CEE	Centre for Environment Education
CPCB	Central Pollution Control Board
CPHEEO	Central Public Health and Environmental Engineering Organisation
CSIR	Council of Scientific and Industrial Research
CSR	Corporate Social Responsibility
DI	Deionised
DL	Dioxin like
ECHA	European Chemicals Agency
EoL	End of Life
EPR	Extended Producer Responsibility
EPS	Expanded Polystyrene
E-waste	Electronic waste
FICCI	Federation of Indian Chambers of Commerce & Industry
FMCG	Fast-moving consumer goods
FTIR	Fourier Transform Infrared
FRP	Fibre Reinforced Plastic
GAIL	Gas Authority Of India Ltd.
GC-MS	Gas chromatography-mass spectroscopy
GDP	Gross Domestic Product
GHCL	Gujarat Heavy Chemicals Limited
GIDC	Gujarat Industrial Development Corporation
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GOI	Government Of India
GPCB	Gujarat Pollution Control Board
GST	Goods and Services Tax
HCCBPL	Hindustan Coca-Cola Beverages Private Limited
HDPE	High Density Polyethylene
HUL	Hindustan Unilever Limited
ICT	Information and communication technology
IEC	Information, Education and Communication
INC	Intergovernmental Negotiation Committee
ILC	Inter-laboratory comparison
IRS	Informal Recycling Sector

ISC	Inter-State Council
ITC	Imperial Tobacco Company of India Limited
INOPOL	India-Norway cooperation project on capacity building for reducing plastic and chemical pollution in India
KC	Kabadiwalla Connect
KVIC	Khadi and Village Industries Commission
LDPE	Low Density Polyethylene
LoI	Letter of Intent
MFA	Ministry of Foreign Affairs
MGC	Mu Gamma Consultants
MLD	Million Litres per Day
MLP	Multi-Layered Plastic
MNC	Multi-National Company
MoEFCC	Ministry of Environment, Forest, and Climate Change
MoHUA	Ministry of Housing and Urban Affairs
MoMSME	Ministry of Micro, Small and Medium Enterprises
MoU	Memorandum of Understanding
MPCB	Maharashtra Pollution Control Board
MPPCB	Madhya Pradesh Pollution Control Board
MRF	Material Recovery Facility
MSME	Micro, Small and Medium Enterprises
MSP	Minimum Support Price
MSW	Municipal Solid Waste
MT	Metric Tonnes
MTTP	Master Trainers' Training Programme
NGO	Non-governmental organization
NIVA	Norwegian Institute for Water Research
NPL	National Physical Laboratory
NREA	National Resource Efficiency Authority
NTPC	National Thermal Power Corporation Ltd
ONGC	Oil and Natural Gas Corporation
PA	Polyamide
PBAT	Polybutylene adipate-co-terephthalate
PC	Polycarbonate
PCC	Pollution Control Committee
PCL	Polycaprolactone
PCPIR	Petroleum, Chemical, and Petrochemical Investment Region
PE	Polyethylene
PET	Polyethylene Terephthalate
PGA	Polyglycolic acid
PHB	Polyhydroxybutyrate
PIBO	Producers, Importers, and Brand owner
PIL	Public Interest Litigation
PLA	Polylactic acid
PMMA	polymethyl methacrylate
POPs	Persistent Organic Pollutants
PP	Polypropylene
PRO	Producer Responsibility Organizations
PVC	Polyvinyl chloride
PWM	Plastic Waste Management
PWMR	Plastic Waste Management Rules
QA/QC	Quality Assurance/Quality Control
RDF	Refused Derived Fuel
REPLAN	REducing PLAstic in Nature
RFID	Radio Frequency Identification
RWA	Resident Welfare Association
SEZ	Special Economic Zone
SHG	Self-Help Group
SMC	Surat Municipal Corporation
SRMIST	SRM Institute of Science & Technology
SOP	Standard Operating Procedures
SPCB	State Pollution Control Board
SRLM	State Rural Livelihoods Mission
STF	Special Task Force

SUDA	Surat Urban Development Authority
SUP	Single Use Plastic
SUPPs	Single Use Plastic Products
TERI	The Energy and Resources Institute
TL	Toxics Link
TPA	Tonnes per Annum
TPD	Tonnes Per Day
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
ULBs	Urban Local Bodies
UNDP	United Nations Development Programme
UNEA	United Nations Environment Assembly
UNEP	United Nations Environment Program
UPC	Un-Plastic Collective
US	United States
USD	United States Dollar
UT	Union Territories
WRAP	Waste & Resources Action Programme
WWF	World Wildlife Fund

Executive SUMMARY

The INOPOL project

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 reduce plastic and chemical pollution from major sources within industry, public sector, and civil society in India. The INOPOL project is led by the Norwegian Institute for Water Research (NIVA), in close collaboration with Mu Gamma Consultants Pvt. Ltd. (MGC), Central Institute of Petrochemicals Engineering and Technology (CIPET), The Energy and Resources Institute (TERI), SRM Institute of Science and Technology (SRMIST) and Toxics Link. The project aims to address the highly interlinked challenges of marine litter, microplastics, and Persistent Organic Pollutants (POPs), with the overarching goals of enhancing capacity to reduce marine litter and microplastic pollution in Gujarat state and building capacity to reduce releases of plastic wastes and POPs in India by supporting the implementation of the Stockholm Convention (SC). The Plastic Waste Management Strategy Report for Gujarat focuses on INOPOL's work in the former domain.

Plastic pollution in Gujarat

The INOPOL project monitored plastic pollution in the catchment areas of the rivers of Tapi (Tapti) and Daman Ganga, along the cities of Surat and Vapi in Gujarat State. These two 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 metropolitan city of Surat, which has experienced significant economic growth and has been estimated to have the highest composition of municipal plastic waste generation of 60 Indian cities as per a CPCB study. Vapi is situated near the banks of Daman Ganga and is the largest industrial area in Gujarat, dominated by chemical and paper industries.

Estimates suggest that waste generation in both Surat and Vapi will increase significantly in the next decade. Gujarat is, and has been over the past decades, one of the fastest growing states in India. It has a strong industrial and manufacturing base which caters to both, the domestic and international market. Some of the leading industrial activities relate to gems and jewellery, pharmaceutical, chemical, petrochemical, textile, pesticide, and fertilizer industries. For example, 25 % of India's plastic is manufactured in Gujarat, largely by Micro, Small and Medium Enterprises (MSMEs). While on the one hand, recent growth has created employment opportunities and prosperity, there are also environmental challenges that accompany this growth, including with respect to plastic and chemical pollution. Gujarat state is the second largest generator of plastic waste in India, with approximately 3,56,873 tonnes per annum in 2018-2019. While a portion of this is captured in the formal and informal waste management and recycling streams, plastic material also escapes from industrial and municipal plastic waste streams. Once this pollution reaches the marine ecosystems through riverine systems, it can have even more significant detrimental effects.

Plastic monitoring in Gujarat

Microplastics (MPs) are tiny pollutants that are a potential biological hazard in the marine environment and a growing environmental concern. Due to their slow degradability, fish and other aquatic living organisms may ingest the particles that may also carry synthetic chemicals and persistent organic pollutants. Primary MPs are those which are engineered to be microplastics and are found to be mostly used in cosmetics, whereas the secondary MPs are because of the fragmentation of larger plastics over time.

Rivers are the major route of plastic debris transport from land-based resources to oceans. The MPs present in the rivers are of different shapes, sizes, and types. To quantify the presence of MP in Surat and Vapi a sampling campaign was organized in the upper, middle, and lower streams of the two river systems for water collection. The visual observation revealed a number of floating plastics which include plastic items such as food packaging, plastic bottles, plastic cups and spoons, medical bottles, plastic caps, plastic woven sacks etc. flowing through the river in a period of 10 mins. Further, the analysis showed the highest concentration of microplastics in the Daman Ganga River was found in Silvassa (S2) with 6.99 pieces/L followed by the location just downstream of the Madhuban Dam just before Rakholi bridge (S1) with 4.35 pieces/L. With regards to the Tapi River it was seen that the concentration of microplastics was higher upstream at Bori Savar village (Located downstream of Ukai Dam) with 3.72 pieces/L (S6) and 2.48 pieces/L (S8) while the concentration at Surat River Front (S9) was found to be 0.93 pieces/L .

A model was set up to supplement and expand the predictive power of empirical data. A key outcome was the illustration of the strong relevance of flooding in the river transport of plastic litter, emphasising the importance of appropriate timing of clean-up campaigns: clean-up campaigns will have far more impact in reducing marine litter if executed before the rainy season (March-April).

Regulatory developments

Over the past 30 years, a range of regulatory and policy interventions have been introduced in India that inform rules, protocols, and guidelines to manage waste at national, state, and local level. Assessing the opportunities and hurdles of such new frameworks, key industry stakeholders reported limited capacities for implementation in the short run and in some cases struggling with the sudden ban on certain Single Use Plastic (SUP) items such as straws - especially considering the lack of viable alternative materials. Nevertheless, several of the key regulatory measures that have been taken have occurred quite recently (e.g., the Single Use Plastic Products (SUPP) ban and the Extended Producer Responsibility (EPR) regulations), the implementation of such will take some time. Hence, adequate support and capacity building is required on state level in the years to come. In parallel the international negotiations of a global treaty on plastic pollution have just commenced, and India would benefit from closing the key knowledge gaps that have been identified in the present report and strengthen domestic knowledge production. This way, India will be better equipped for the negotiations.

Integration of the informal sector

Another key component in India's waste management system is the informal recycling sector (IRS), which is estimated to consist of 2-4 million people, that recycles 20-60% of the total recyclable waste. A mapping of the contribution, functioning and challenges in Surat and Vapi was carried out in collaboration with Kabadiwalla Connect (KC). The findings showcase a detailed account of the role that the different actors play along the value chain in the waste management stream, their socio-economic status, as well as value creation. The study documents the large volumes and values of post-consumer recyclable waste that are processed by the IRS, as well as its active role to supplement existing, formal municipal waste management systems. Such state-specific data will contribute to promote effective recycling, and understanding gaps, while promoting a just transition of the IRS. Given the potential adverse health impacts of plastic and chemical pollutants within the IRS also underlines the public health dimension in the sector.

Outline

The aims, objectives, and context of INOPOL are outlined in **Chapter 1** of this Plastic Waste Management Strategy report. **Chapter 2** presents the overarching project background and a detailed description of the pilot catchment areas and study sites. This includes information on current waste composition, its management and recent policy developments as well as relevant hydrological, demographic, socio-economic and pollution data. **Chapter 3** presents the monitoring protocols, methodological approaches for the sampling and analysis of macro and micro plastics in the catchment areas. It also presents the results and seeks to address the issue of existing data gaps and limitations. **Chapter 4** provides an overview of key plastic pollution sources in the catchment areas, as well as the modelling of various scenarios in the river transport of plastic waste to the ocean. **Chapter 5** discusses key considerations when creating impactful policy regimes, which are to include key stakeholders (e.g., industry, consumers, civil society) in the process of formulation, as well as consider market implications, institutional capacity for compliance or technological access for their implementation. **Chapter 6** delves into recent conceptualisations, international and national perspectives, frameworks and model initiatives that hold promise and inform the direction of addressing plastic pollution in future. **Chapter 7** proposes the recommendations and way forward from this study in order to strengthen the science-policy-society interphase.

The proposed actions in this report are closely aligned with the goals and strategies of the Indian Plastic Waste Management Rules, including the recent EPR and SUPP-ban amendments, as well as international frameworks such as the Basel Convention, the Stockholm Convention (POPs and plastic interactions) and the ongoing global plastic treaty negotiations. Further, the report will make contribution towards achieving the UN Sustainable Development Goals (SDGs) related to chemicals and wastes, including 2.1, 3.9, 6.3, 11.6, 12.4, 12.5, 14.1 and 16.1.

CHAPTER 1
AIMS AND OVERVIEW

1.1 Introduction

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 reduce plastic and chemical pollution from major sources in India. The INOPOL project is led by the Norwegian Institute for Water Research (NIVA), in close collaboration with Mu Gamma Consultants Pvt. Ltd, in cooperation with contributing partners including the Central Institute of Petrochemicals Engineering and Technology (CIPET), the SRM Institute of Science and Technology, The Energy and Resources Institute (TERI) and Toxics Link. The **main goal** of the project is to provide science-based knowledge that will support India's ambitious targets to reduce plastic releases and enhance its efforts to implement the Stockholm Convention on Persistent Organic Pollutants (POPs). Aiming to support and advise decision-making the project will produce knowledge that is relevant to the Indian situation and accelerate capacity to tackle plastic and chemical pollution from important sources within key industries, the public sector, and civil society in India.

The project has addressed highly interlinked and key challenges regarding marine litter, microplastics, and POPs in India. The collaboration builds on the well-established and successful partnership between NIVA and Indian institutions. The project has been carried out in close alliance with national and selected state authorities.

Activities Involved

- Identification of key sources and hotspots of plastics and new POPs
- Establishment of a baseline for plastics and new POPs
- Review of Best Available Technology (BAT) and Best Environmental Practices (BEP)
- Develop monitoring capacity of the Gujarat Pollution Control Board (GPCB)
- Develop the analytical capability for microplastic and 'new' POPs
- Develop increased awareness in the industry
- Develop management tools, increased capacity, and awareness
- Training and capacity-building programs
- Develop strategy reports for key sectors
- Develop a state-specific action plan
- Field training on 'new' POPs and Plastic management
- Identification of social and economic drivers in POPs and plastic management
- Cost-effectiveness analysis
- Develop knowledge on links between plastics and POPs

Outputs of the Project

1. **The outputs under the Outcome "Reduced marine litter and microplastics pollution in India" are:**
   a) Baseline for land-based sources of marine litter and microplastics established
   b) Monitoring capacity strengthened
   c) Societal drivers assessed, and awareness enhanced
   d) Tools for management of marine litter and microplastics developed
   e) Socioeconomic and societal impacts of measures assessed
   f) Plastic Waste Management Strategy Report: Gujarat
2. **The outputs under the Outcome "Reduced releases of POPs supporting the implementation of Stockholm Convention" are:**
   a) Baseline for use and release of new POPs established, including links to plastic pollution
   b) Monitoring capacity strengthened
   c) Tools for management of new POPs established
   d) Enhanced policy and management addressing social and economic impacts and best practices
   e) Capacity building and training carried out and awareness raised
   f) Action plan for new POPs in Gujarat

Outcome of the Project

The INOPOL project is targeted towards the outcomes under the Norwegian Development Assistance Program:

1. Improved waste management infrastructure and systems for waste management from land-based sources
2. Waste cleaned up from selected rivers and waste properly managed
3. Private sector's sustainable production, use, and responsible waste management
4. Strengthening of national and regional instruments to prevent marine litter and microplastics and POPs

Chapter 2
APPROACH AND METHODOLOGY

2.1 Case study area, catchment and sampling sites

This project focuses on the catchment areas of rivers Tapi and Daman Ganga, in Gujarat with the industrial centres of Surat and Vapi respectively. These locations contribute significantly to plastic pollution and the catchments to which they belong have the potential of transporting plastics to oceans.

2.1.1 Case Study Location

The State of Gujarat was chosen as a pilot with the potential of scaling up similar efforts at the national level. With an area of 196,244 km^2 and a population projected to be nearly 70 million in 2021, Gujarat has become a state with one of the fastest industrial growth rates in India. The economic landscape is dominated by pharmaceutical, chemical, petrochemical, textile, pesticide, and fertilizer industries. The two catchment areas, described in detail in section 4.1, cover parts of the Gujarat State (Figure 2.1.1). The Tapi River flows through the city of Surat, an urban industrial hub, and the Daman Ganga River flows through the city of Vapi, another industrial hub. Based on socioeconomic, geographical, and ecological factors, these catchments are likely to be contributing to plastic and chemical waste in the marine ecosystem.

2.1.2 Catchment

The Tapi River is the Peninsula's second-largest westward draining river with a catchment area of 62 225 km^2. At the mouth of River Tapi, Surat is located

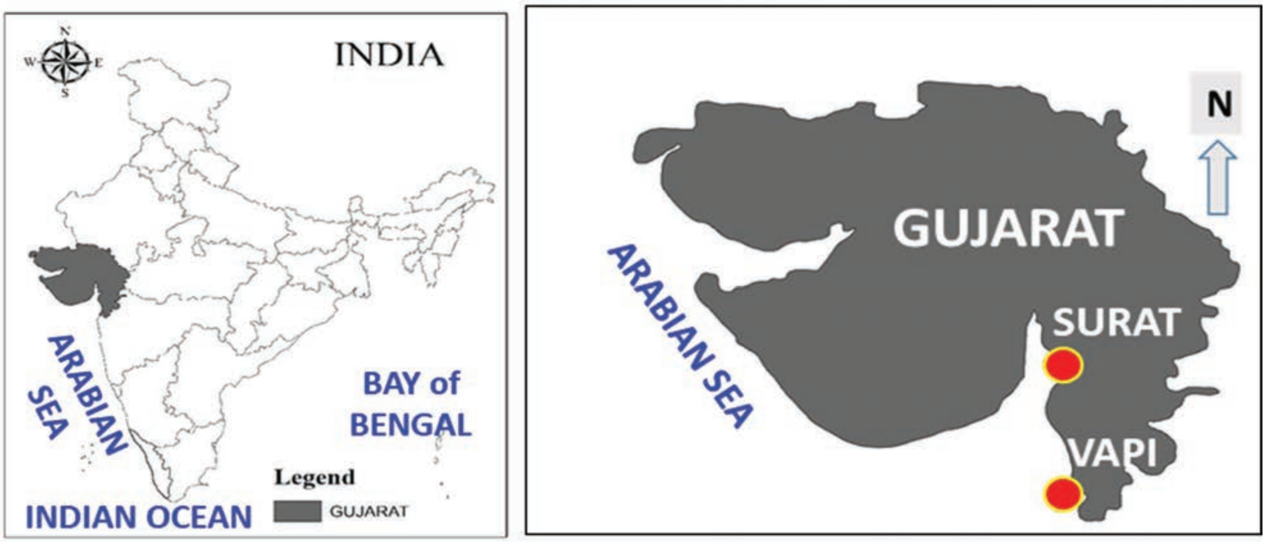


Figure 2.1.1. Study location (Google Maps)

at 21.1702° N latitude and 72.8311° E longitude. The industrial city is also India's ninth-largest urban agglomeration and one of the world's fastest urbanizing cities. Surat has the highest composition of municipal plastic waste generation of 60 Indian cities (GPCB, n.d.; CPCB, 2015) while it is also ranked by the *Swachh Survekshan* ranking (Star Rating for Garbage-Free Cities) as the second cleanest city in the country for the years 2020, 2021 and 2022 consecutively.

The Daman Ganga River which originates from the Sahyadri hills in Maharashtra drains into the Arabian sea is 131.30 km long and has a total catchment area of 2318 km^2. Vapi city is located at 20.3893° N latitude and 72.9106° E longitude and houses Asia's largest industrial area and has small-scale, chemical-based industries as well as plastic recycling units. The Vapi Industrial Estate started by Gujarat Industrial Development Corporation (GDIC) in 1967, stretches over 11.4 km^2 and houses more than 1400 industries, mostly small and medium enterprises largely manufacturing chemicals and paper.

Figure 2.1.2. Satellite images of river mouth. (Google Earth, 2022)

2.1.3 Sampling Sites

The sampling sites were determined based on:

a) the catchment area covering upstream, midstream, and downstream of the two river systems (of Tapi and Daman Ganga) in the cities of Surat and Vapi in Gujarat;

b) hotspots along urban and suburban transects including industrial discharges, open dumpsites, and healthy wetlands.

For plastic waste, the samples included surface water and debris from the sites selected as indicated in Figure 2.1.3. Surface water samples, as well as debris, were collected during two sampling campaigns in December 2020 and September 2021 and analysed.

In total, 25 surface water samples were collected in December 2020 and 24 surface water samples, and 1 debris sample were collected in September 2021. Annexure 1 presents details of the sampling locations.

Tapi River

Urban Centre – Surat

Population (Million): 4.4 (2011)
7.1 (2021 estimated)

Urban Area: 474.2 km

Waste Generation: 2200 TPD

Daman Ganga River

Urban Centre – Vapi

Population (Million): 0.16 (2011)
0.19 (2021 estimated)

Urban Area: 22 km

Waste Generation: 50 TPD

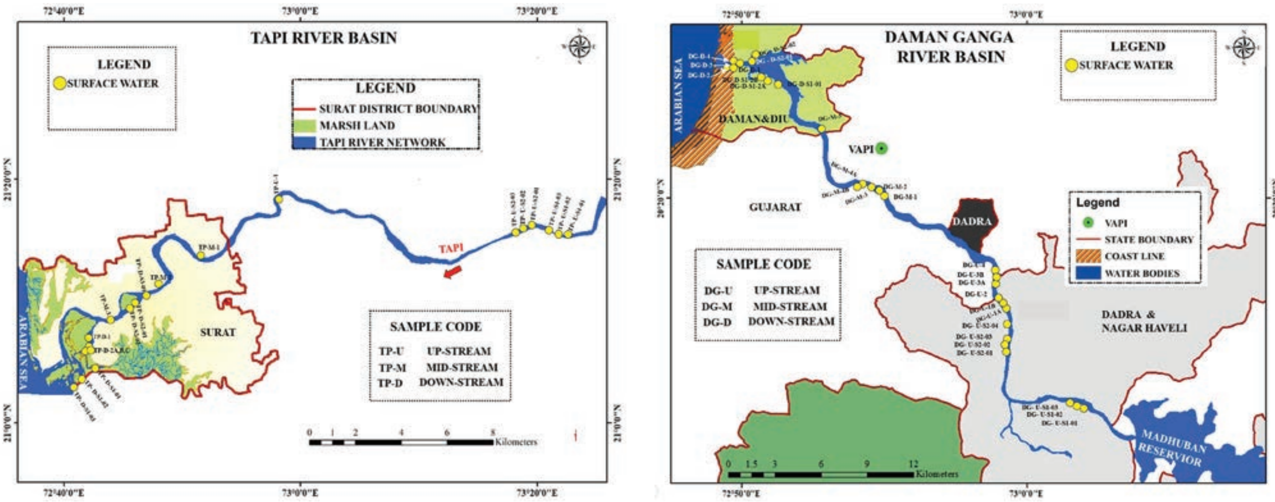


Figure 2.1.3. Sampling sites.

2.2 Socio-economic context, local and national policy and regulation, management practices and existing capacity and expertise

2.2.1 Socio-Economic Context

Surat, also referred to as “Diamond City” is one of India’s largest urban agglomerations with a GDP of $59.8 billion. The city houses a population of 4.6 million in 2011, with a density of 13,680 persons per km^2 (Census of India, 2011). With increasing population and industrial footprint, the Surat Municipal Corporation (SMC) reported that the city generates 2200 M.T. of municipal solid waste per day of which 2150 M.T per day on an average is collected and transported. Surat is known to house major industrial entities like Reliance, Gas Authority Of India Ltd. (GAIL), Oil and Natural Gas Corporation (ONGC), Essar, Ultratech Cement and Ambuja Cement to name a few. The diamond cutting and polishing exports from the city account for about 90% of the overall global exports (World Economic Forum and PWC, 2017). The Surat Urban Development Authority (SUDA) houses the industrial hub at Hazira town at the outskirts of Surat city.

The city has also been selected under the ‘Smart City Mission’ launched by the Ministry of Housing and Urban Affairs (MoHUA), GOI, for upgrades in various sectors including IT, renewable energy, solid waste management along with town planning and development.

Vapi is referred to as the most industrialized city in Gujarat followed by Ahmedabad, Surat, and Vadodara. The city houses a population of 1.6 million as per 2011 census, with a population density of 7292 persons per km^2 (Census of India, 2011). The city generates 50 TPD of municipal solid waste (Valsad District Committee, 2019) and is divided into 14 administered wards to manage its increasing population and pollution. While the western part housed the original town, the eastern section is home to the industry and newer residential areas. Vapi is well known for being a core chemical-based industrial hub dominated by paper and chemical-based industries. The Vapi industrial estate is spread over an area of 1163.77 ha (11.64 km^2) (Central Ground Water Board, 2015) with over 300 medium and large-scale industries (MSME, 2018). With its increasing population and industrial dominance, Vapi has developed Asia’s largest Common Effluent Treatment Plant (CETP) which is being currently administered by Vapi Nagar Palika.

2.2.2 Regulation and policy at National and local Level

The Environment Protection Act was enacted in 1986 under Article 253 of the constitution after the Bhopal Gas Tragedy. In 1996, a public interest litigation (PIL) was filed in the Supreme Court against the GOI and the municipal corporations responsible for solid waste management, prompting the formation of a committee to address the problem. The committee's final proposal was submitted in the year 1999. The Ministry of Environment, Forest and Climate Change was then assigned with the responsibility to develop appropriate rules for municipal solid waste management. In the year 2000, the Municipal Solid Waste Management Rules were notified. This was followed by the drafting of the service level benchmarks in the year 2008, Plastic waste management rules in 2011. On March 18, 2016, the Government introduced the Plastic Waste Management (PWM) Rules, 2016, which replaced the Plastic Waste (Management & Handling) Rules, 2011 (MoEFCC, 2016). The 2016 rules were amended again in 2018, 2021, and 2022.

The amendment of Plastic Waste Management (PWM) Rules, 2016 mandates that carry bags made of virgin plastic must have a minimum thickness 120 microns. In the August 2021 amendment, GOI (GOI) included key definitions such as 'Single Use Plastic', 'Plastic waste processing' and 'non-woven plastic bag'.

In the February 2022 amendment, there has been a focus on collection, reuse and reclying of plastic waste in addition to the development of a formula to calculate the liability of actors along the waste value chain. The recent amendments also focus on developing the infrastructure and registration of Producer, Importer, Brand owner (BO) and plastic waste processors by SPCB/PCC through the centralized Extended Producer Responsibility (EPR) portal developed by CPCB. The EPR targets for the respective stakeholders and certificates have also been introduced.

The Surat Municipal Corporation (SMC) lays down Public Health Bye-laws for the city wherein local regulations of solid and liquid waste management, air and noise pollution along with other sanitation and public health aspects are covered (SMC, 2016).

2.3 Waste generation data and collection rates

The Surat city generates 2320 TPD of Municipal solid waste with 0.45 kg per capita per day in 2019-20. Plastic waste generation in Surat was the highest among the 60 cities as per the CPCB and CIPET study of 2010-2011 – containing 12.47 % of plastics in MSW (GPCB, n.d.; CPCB, 2015). As per SMC, the share of plastics has now increased to 19 %.

For estimating waste generation in Surat city different parameters and methodologies have been used, providing an insight into behavioural aspects and standards to estimate waste. The very first is to estimate the population till 2041 (CPCB, 2018) based on Central Public Health and Environmental Engineering Organisation's (CPHEEO, 2016) formula for Geometrical Increase and the second is to calculate exponential growth rate based on existing MSW generation trends from data provided by SMC. The quantity of plastic that would reach oceans will be estimated based on other factors like the flow of rivers and drainage.

In Vapi, plastic waste estimation is calculated based on the recent District Environmental Action Plan Report for Valsad District which states *plastic composition in MSW corresponds to 2% in Vapi (*Valsad District Committee, 2019*)* According to the 2019 Valsad District Environmental Action Plan report, Vapi generated 1 TPD of plastic waste, accounting for 2% of plastics in Vapi MSW (Valsad District Committee, 2019). However, due to a lack of waste characterisation studies in the city, determining the properties of the plastic waste generated in Vapi is difficult. Because of its proximity to Vapi (11 km) the features of Daman's plastic waste can be used to anticipate the characteristics of Vapi's plastic waste. Daman was one of sixty cities studied in the CPCB-CIPET assessment in 2011, and the city MSW had 4.64 percent plastic waste (CPCB, 2015).

2.3.1 Management practices and existing capacity and expertise

The Gujarat state has 1049 plastic manufacturing units, 12 compostable plastic units, and ten multi-layered plastic units. There are also around 18 recycling units in Vapi and 3 units in Surat with others distributed in the various other districts of the state.

The Surat Municipal Corporation is the authorized body designated to manage municipal solid waste in Surat city. To attain a high material processing efficiency, it used a multi-pronged approach that included 100% source segregation, investment in building, operation, and maintenance, and channelization of recyclables and refuse-derived fuels. Surat Municipal Corporation has set up eight collection points for plastic debris. The facility has processed 28,000 tonnes of plastic waste so far. The processing plant currently has a capacity of 75 TPD, with the ability to expand to 200 TPD in the future. The Surat-*Khubsurat* campaign motivated the citizens to make Surat one of the cleanest cities in India, which significantly influenced the city's governance. Surat Municipal Corporation has made street sweeping and waste collection a sign of commitment. Within six months a centralized and subsequently decentralized waste collection and disposal system was implemented. The authorities placed public health and hygiene at the top of its agenda, and with citizen backing, good gains were achieved. Separate wards, zones, and districts were established to ensure that all regions were cleaned efficiently and effectively (Biswas et. al., 2021)

In Vapi, Vapi Nagar Palika is the authorized body designated to manage municipal solid waste in the city. According to the municipality, the city generated a total of 50 tons of waste per day. The MSW dumpsite covering 4046 m^2 in Vapi is located beside the river Daman Ganga at Chandor Village where the waste is dumped directly without scientific processing. The city lacks waste characterization studies, which has resulted in waste being dumped without being properly processed. Existing capacity and expertise of PWM in India

- Presently, there have been multiple areas where plastic waste is being utilized, such as construction of roads, building materials, co-processing of plastic waste in cement kilns, generation of Refused Derived Fuel (RDF) etc.
- The usage of shredded plastic in the construction of roads has been effective in reducing the huge quantity of plastic waste. The Ministry of Road Transport and Highways, GOI in November 2015, mandated the use of plastic for building roads in conjunction with bituminous mixes. India has constructed over one lakh kilometre of plastic roads (Swachh India, 2018). In at least 11 states as on date. The advantages of plastic roads include resistance to potholes, cost-effective, and increased durability to adverse weather conditions. It should be noted at the same time that there are Several environmental and health concerns when plastic is used in road construction.
- Apart from construction of roads, plastic waste is also being used to make building materials from plastic. India's Council of Scientific and Industrial Research-National Physical Laboratory (CSIR-NPL) has developed and patented a sustainable process for producing tiles from plastic waste. They also plan on building a recycling plant with a monthly production capacity of 5 lakh tiles to generate more materials so that the maximum utilization of plastic waste can be achieved.
- Another innovative use of PET Bottles was found to be done by a petro-chemical based company to produce textile products by collecting waste from more than 150 vendors across the country.
- Gujarat, Madhya Pradesh, and Meghalaya are among the states/UTs that are sending their plastic

waste to cement facilities for co-processing. Due to the availability of cement factories in Gujarat, co-processing of plastic waste in cement industry is considered. High temperature and residence duration in cement kilns are advantages of co-processing plastic waste in cement businesses, with the latter resulting in a reduction in overall greenhouse gas emissions.

- RDF is made from a variety of domestic and commercial waste, including plastics. Contaminated plastics, multilayer packaging, and other plastic packaging materials are usually disposed of in landfills. These wastes can be processed and transformed into RDF, which has a high calorific value and can be utilized in a variety of sectors as an alternative fuel.

Chapter 3
SAMPLING AND MONITORING (MICRO- AND MACRO-PLASTICS)

3.1 Concentrations and fluxes of litter and plastics determined in selected catchments

Key points

- It is assumed that most of the plastics (macro or micro) in the environment originate from land-based sources, entering aquatic habitats through release or transfer into rivers. To better understand the risks that plastic pollution poses on aquatic ecosystems and quantify its risk, knowledge on riverine plastic transport is needed.
- Although rivers are the main pathway to convey plastic to marine systems, the sources of these plastics include industries present along the banks of these rivers.
- The cities of Vapi and Daman sit on the the Daman Ganga and the city of Surat is located on the downstream section of the Tapi. Numerous textiles and plastics industries, power plants, petrochemical refineries etc. in these cities contribute to the mass concentration of plastics present in the rivers.
- Assessment of these plastics is important to better understand the origin, transport and fate of these plastics entering in the marine system.

3.1.1 Introduction

Generally, plastic waste is recycled or burned, while some is discarded or disposed off in landfills or the environment. Plastics typically emanate from land-based sources and are primarily transported through freshwater systems such as rivers (Nelms et al., 2021) and into the oceans (Mihai, 2018). Upon exposure to an environment, degradative forces take effect and plastic items input into the rivers from these land-based sources (e.g. macro-plastics) begin to disintegrate into meso (5-25 mm in size) and micro (<5mm in size) plastics (Blettler et al., 2017).

The majority of plastic waste produced in India comes from 10 major cities which includes Ahmedabad and Surat in Gujarat state (Vishwa Mohan, 2019). The list of these 10 major cities along with amount of waste produced is listed in Figure 3.1.1. Gujarat, being a major industrial hub in the country, produces around 408,201 tons per day (TPD) of plastic waste. The state houses 1049 registered plastic manufacturing units, 12 compostable plastic units, and 10 multi-layered plastic units (CPCB, 2021). Two major industrial cities, Vapi and Surat are located on the banks of the rivers Daman Ganga and Tapi respectively, and both the rivers drain into the Arabian Sea. The rivers act as a lifeline to these cities as they are the major source of fresh water. In recent times, the rivers have become contaminated with plastic litter from industrial discharges and dumping of waste in riverine areas. It is important

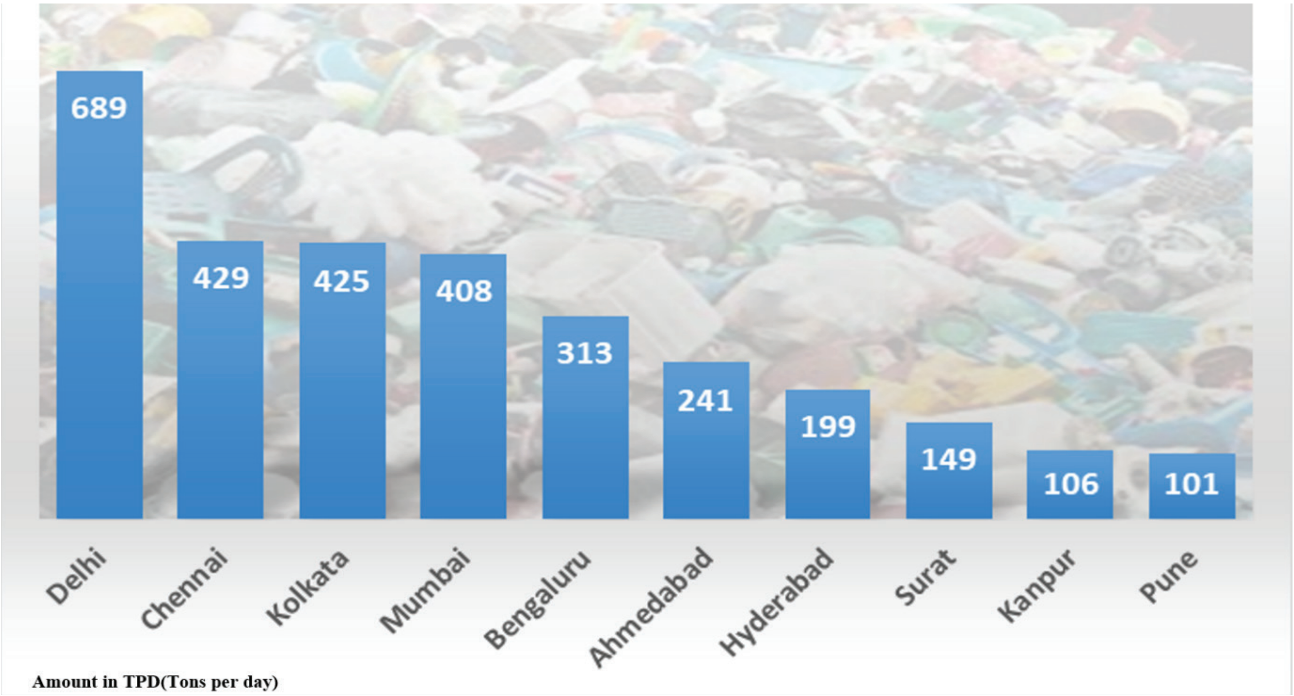


Figure 3.1.1. Top 10 cities generating plastic waste in India.
Source: CPCB (2015) *Data rounded off

to understand the concentration of litter and the impact of this plastic flux on riverine and marine environments.

3.1.2 Area survey

The Tapi River in Surat and the Daman Ganga River, which flows through Vapi and Daman, were selected as the focus areas of this survey (see Figure 3.1.2).

Surat and Vapi lie among the major plastic waste generating cities in the state of Gujarat. The cities also exponentially produce Municipal Solid Waste (MSW), among which there are non-biodegradable waste types which include of plastics and packaging materials. MSW generation is estimated to increase more than 2-fold and more than 5-fold in Surat and Vapi, respectively, between 2021 and 2041 (Table 3.1.1.).

(a) (b)

Figure 3.1.2. Daman Ganga and Tapi River meeting the Arabian Sea (Google Earth, 2022)

Table Table 3.1.1. shows plastic waste generation (TPD) spanning four decades in the cities of Surat and Vapi.

Table 3.1.1. Plastic waste generation in Surat and Vapi from 2011-2041 (Akshey Bhargava., et al. 2022; INOPOL, 2021)

	Plastic Waste Generation (TPD)	
Year	**Surat**	**Vapi**
2011	536.02	0.792
2021	783.05	1.854
2031	1143.57	4.335
2041	1668.68	10.133

3.1.3 Monitoring Plastic Fluxes in the Catchment Areas of Tapi and Daman Ganga

3.1.3.1 Inflow of plastics fluxes into the rivers

The Tapi and Daman Ganga Rivers receive plastics, mainly from the nearby cities/districts. In the Daman Ganga River, the union territories of Daman and Diu and Dadra and Nagar Haveli contribute substantially to plastic pollution from various industries and mishandling of waste, such as from solid waste, construction and demolition waste, bio-medical waste, electronic waste (E-waste) etc. This is also the case for major cities along the Tapi River, including Jalgaon and Dhule in Maharashtra state and Surat in Gujarat state. Table 3.1.2 shows the total amount of waste that these cities/territories collectively produce from these industries.

3.1.3.2 Sources of Plastics in the rivers

a) Industrial Units: Cities along the rivers discharge a large number of effluents. Surat, one of the major industrial cities of Gujarat, is on the Tapi River. It houses major industries like Kribhco, NTPC, Reliance, Essar, and L&T along with numerous ports and power plants like Ukai and Kakrapar. Plastics and petrochemical industries, and synthetic textile mills release industrial effluents into the river (MSME, 2018). The Daman Ganga River is also polluted by similar industrial effluents. There are several common effluent treatment plants (CETPs) located in the river, including those of the Gujarat Industrial Development Corporation (GIDC) in Vapi and Khemani Distillery Limited (KD) in Daman. Heavy metals, bacteria and protozoa are discharged with petrochemical waste into these rivers, which can contaminate sediment and threaten fisheries and other invertebrates. Often, petrochemical effluents accumulate along the shorelines of rivers and cause ecological damage to the near-shore community (Nene et al., 2020).

b) Rural and Urban Units: Dumping of plastics and solid waste in riverine areas or direct dumping into the aforementioned rivers results in a significant macroplastic flux that may be released into the ocean. Macroplastics that are typically observed fall into size range 2.5-50 cm (van Emmerik et al., 2019). Common polymers like polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), and expanded polystyrene (EPS) can be found in the form of carry bags, bottles, food packaging,

Table 3.1.2. Inflow of types of waste into the rivers from industries and local bodies present in nearby cities. (Union Territory of Daman, Diu and Dadra Nagar Haveli, 2021; MPCB, 2019)

Types of Waste	Daman Ganga	Tapi
Solid Waste	175 MT/day	340 MT/day
Bio-Medical Waste	250 kg/day	1142 kg/day
Hazardous Waste	2961 (approx.) MT/Annum	1132.41 MT/Annum
E-Waste	7.022 MT/Annum	----

straws, cigarette butts, and EPS products. Other sources of plastic waste include fishing gear, e-waste, bio-medical waste, etc. Fishing is prevalent in both the Daman Ganga and Tapi rivers. Plastic litter consists of PP ropes and nylon nets used for fishing (Nelms et al., 2021). Industrial clusters, domestic sewage, solid waste, open natural drains area major sources of plastic pollution to the Daman Ganga River and the Arabian Sea (Daman Ganga, 2019). E-waste sometimes contains heavy metals and plastics that contribute to plastic litter in rivers. E-waste migrates from burning sites where they are generally incinerated or end up in the rivers as a result of surface runoff through heavy rainfall or storms (Chatterjee, 2011). Bio-medical waste has recently become an emerging plastic pollutant in the rivers since the rise of COVID 19 (Chakraborty et al., 2022). This includes different personal protection equipment (PPE), such as face masks, face shields, and gloves, which are often made of plastics like PP, polycarbonate (PC), and cellulose, Polycarbonate(PC), Polyethylene terephthalate glycol (PETG) (Henneberry, n.d.).

c) Miscellaneous Sources: Some other sources of plastics to rivers include the immersion of idols, rituals, or festivals performed on the banks of the rivers. This increases the suspended load and the level of plastics and other pollutants in the river. Tourism also adds to the influx of plastic litter. For example, Nani Daman Fort lies on the banks of the Daman Ganga River where it meets the Arabian Sea and is a major tourist attraction in Daman. As observed during the field trip, the river has accumulated micro- and macro-plastic litter, which consist of small plastic beads to large PET bottles that end up in the Arabian Sea.

3.2 Interlaboratory comparison study (ILC)

No standard method has emerged for the determination of microplastic content in environmental samples. This in part reflects the wide variety of different sample types that have been investigated for microplastic contamination, as well as the diverse suite of contaminants included within the term 'microplastic' (e.g., different sizes, shapes, polymer types/chemical compositions). It is necessary to calibrate analytical efforts to ensure a high quality of data and comparability between results generated by different laboratories. Beyond this, there is also an international demand to harmonise methods for microplastic analysis (Hartmann et al., 2019).

Inter-laboratory comparison (ILC) studies play an important role in assessing the quality of measurements conducted in laboratory analyses (Molenaar et al., 2018). Participating laboratories are provided with identical, standard test materials and instructed to measure a target analyte using either a standard protocol or their own internal method. This can evaluate the performance of a given laboratory or method, based on the accuracy and precision of reported results. To this end, an ILC exercise for microplastic analysis was hosted within the INOPOL project, with the intention of continuation in the subsequent phases of the project.

3.2.1 Aims and objectives

The overall aim of the microplastic ILC was to harmonise between the analytical procedures used by the participating laboratories in the SINOPLAST project. Harmonisation can be achieved by identifying and explaining potential differences in results and converging methods towards outcomes that are comparable. Undertaking an ILC exercise can reveal these differences and point towards probable causes. To accomplish this aim, two main objectives were established to evaluate the performance of participating laboratories: 1. to accurately identify common polymer types using a chemical characterisation technique; and 2. to isolate and characterise microplastic particles – i.e., quantification of particles and identification of polymer type.

3.2.2 Format and materials

Three laboratories located at INOPOL partner institutions participated in the study; hereafter referred to as Lab 1, Lab 2, and Lab 3. The ILC exercise was composed of two activities, designed to address the two objectives: 1. analysis of plastic pre-production pellets for determination of polymer type (Objective 1); and 2. isolation of microplastic particles from pressed powder effervescent tablets and subsequent quantification and determination of polymer type (Objective 2).

All the test materials were packaged into blister packs (Figure 3.2.1.) with each blister containing either a plastic pellet or a tablet (Figure 3.2.2.). Blisters 1-8 contained plastic pellets composed of eight different common polymer types: polypropylene (PP), polystyrene (PS), nylon (specifically, PA-6,6), polyethylene terephthalate (PET), polyethylene (PE), polycarbonate (PC), poly(methyl) methacrylate (PMMA), and expanded polystyrene (EPS). Blisters 9-12 contained the tablets: three were spiked with known abundances of microplastic particles of different polymer types, whilst the fourth was a blank tablet. The identity of the tablets was not revealed to the labs prior to analysis. The spiked tablets each contained microplastic particles composed of a single polymer type (PE, PS, and poly(vinyl) chloride – PVC). The tablets were produced by the NIVA Microplastic laboratory following well-established protocols that have previously been used to supply several other international ILC exercises for microplastic analysis. A protocol was provided to instruct the labs how to use the tablets, release the microplastics, and isolate them for quantification and analysis.

Several of the participating laboratories were new to microplastic analysis. Prior to the commencement of the ILC, the labs were invited to a workshop on microplastic analysis to introduce their teams to the practical aspects. In addition, a series of protocols, covering different aspects of microplastic analysis, and links to reference databases for FTIR and Raman analysis were provided.

3.2.3 Summary of results

3.2.3.1 Plastic pellet analysis

The performance of the participating laboratories varied for the pellet analysis (Table 3.1.3.). Only a single laboratory – Lab 1 – successfully identified all the polymer types. Lab 2 correctly identified 5 of the 8 polymers, whilst Lab 3 got 2 correct.

3.2.3.2 Tablet analysis

Lab 1 was able to identify the presence of plastic polymers in the tablets but did not quantify polymer concentrations. The correct polymer was not always found in the tablet and polymers were also detected in the blank tablet. Labs 2 and 3 were not able to find the plastic particles that were present in the tablets.

Figure 3.2.1. Picture of the box and test strip for the ILC exercise. Each blister is identified with a numbered sticker.

Figure 3.2.2. Examples of different types of plastic pellets and a pressed powder tablet used in the ILC.

Table 3.1.3. Results from the pellet analysis. Reported results are shown as provided by each laboratory. Incorrect results are indicated in bold text and italics. Note that polyethylene terephthalate is in the polyester group of polymers, so polyester is also an acceptable result for the polyethylene terephthalate pellet.

Polymer composition of plastic pellet	Reported polymer types		
	Lab 1	Lab 2	Lab 3
Polypropylene	POLYPROPELENE (MA-g-PP)	Polypropylene	**Low-density polyethylene (LDPE)**
Polystyrene	POLYSTYRENE	Polystyrene	**Polycarbonate (PC)**
Polyamide (Nylon)	NYLON (Polyamide)	**Polycarbonate**	Nylon
Polyethylene terephthalate	POLYESTER (PET)	Polyethylene terephthalate	**High Density Polyethylene (HDPE)**
(High density) polyethylene	POLYETHYLENE	Polyethylene	**Polypropylene (PP)**
Polycarbonate	POLYCARBONATE	**Polyvinyl chloride**	**Polyvinyl Chloride (PVC)**
Poly(methyl methacrylate)	POLYMETHYL METHACRYLATE (PMMA)	**Polytetrafluoroethylene**	**Polyethylene terephthalate (PET)**
(Expanded) polystyrene	POLYSTYRENE (Expanded Polystyrene Beads)	Polystyrene	Polystyrene (PS)

Other particles, with different physical and chemical characteristics to the spiked particles, were found instead.

3.2.4 Reflections

The variable performance in the plastic pellet analysis exposes a key challenge for new laboratories to embark on microplastic analysis: analytical instruments for chemical characterisation vary and different protocols are needed to facilitate effective analysis using different techniques, analytical modes, and for different models or manufacturers. Following the ILC, guidance was given to the laboratories on common methods to improve the quality of chemical analyses; however, more detailed protocols may be needed for performing microplastic analysis on specific instruments.

Another critical challenge is that analytical instruments commonly used for chemical characterisation of microplastic are not specifically designed for this purpose, and methods are needed to adapt common operating instructions to be effective for microplastic particles. This aspect was in part demonstrated by the performance of Lab 1 in the tablet analysis. Namely, standard methods for undertaking analysis using their instrument – a pyrolysis gas chromatography mass spectrometer – are not optimised for plastic polymers. New methods are required to interpret raw data outputs and quantify microplastic contents. This factor is important to keep in mind when establishing guidelines to laboratories that are likely to use a variety of different analytical techniques and with varying levels of prior experience.

The outcome of the pellet analysis could also be improved by using common reference databases for interpretation of chemical characterisation data or common reporting guidelines. There was some variability in the terminology used for different polymer types (Table 3.1.3.), which could represent a hindrance to efficient harmonisation. International agreement on definitions, terminologies, and reporting is needed to converge microplastic analysis performed in all labs toward comparability.

The performance of all labs in the tablet analysis indicates that particle losses may occur during the isolation of microplastic for analysis. This highlights another important aspect relevant for effectively analysing microplastic content of samples: the way in which these contaminants differ from many other contaminants that are, for example, dissolved or present in other forms. Analytical methods must be further developed, optimised, and validated to ensure that effective and efficient particle recovery is achieved with each analysis. This highlights the need for standard quality assurance and quality control (QA/QC) procedures.

Contamination from the laboratory environment is known to be a persistent problem for many laboratories (Prata et al., 2021; Wesch et al., 2017). Stringent contamination control measures are typically required to reduce the input for particles from the laboratory atmosphere, for personnel, or from containers, apparatus, or reagents. Background contamination was observed in all of the participating laboratories. Guidance to reduce this was provided to the labs; although, it is important to recognise that contamination reduction is an ongoing task for all laboratories engaged in microplastic research.

The INOPOL ILC for microplastic analysis was successful in identifying the main barriers to performing effective microplastic analysis at the participating laboratories. Further work is needed to build capacity in the labs, but this can now be tailored towards specific aspects and achieved more efficiently. Finally, it is important to note that the development of optimised and validated analytical methods and harmonisation of microplastic analysis remains an ongoing task for all laboratories globally, and efforts are still required to establish international agreement regarding definitions, terminologies, and reporting standards.

3.3 Micro- and macroplastic sampling campaign (monsoon/post monsoon) and analysis

- A microplastic sampling campaign was carried out in December 2020 (post monsoon) and September 2021 (monsoon).
- Sampling was conducted on the Daman Ganga and Tapi rivers in Vapi and Surat respectively as well as upstream and downstream of these cities, respectively.
- Some important aspects that need to be addressed while monitoring water samples are: field sampling procedures and accurately analysing microplastic particles.
- Knowledge on the methods and procedures for collecting and analysing samples of microplastics in a marine environment are briefly described.

3.3.1 Introduction

Microplastics are a ubiquitous contaminant of the aquatic environment. However, limited monitoring has been carried out in Daman Ganga and Tapi Rivers in Gujarat thus far. The objective of the sampling is to quantify the levels and composition of microplastic pollution in surface water samples. Major cities located on their banks represent an ideal setting for microplastic research. The presence of many industries in these cities is expected to contribute to the accumulation of microplastics in these rivers.

3.3.2 Selection of sites

3.3.2.1 Meteorological Conditions

The distribution of microplastic pollution in rivers is influenced by factors such as meteorological or hydrological conditions and the proximity to microplastic sources, as well as the spatiotemporal variability associated with these.

Sampling campaigns were carried out in December 2020, representing the post-monsoon season, and

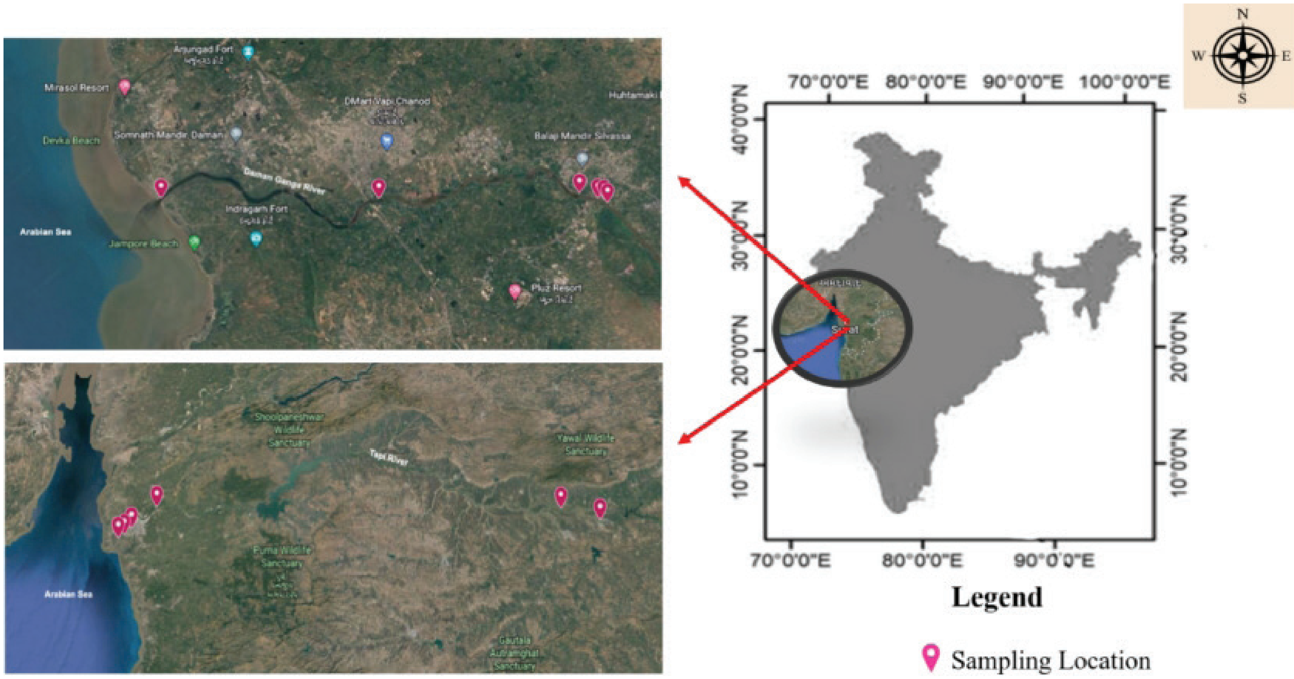


Figure 3.3.1. Sampling locations of Daman Ganga and Tapi River in the month of December 2020 (post monsoon)
Source: (Google Maps, 2022)

September 2021, which was during the monsoon season. In December 2020, the weather in Vapi and Surat was cool and breezy with the temperature in the cities in the range of 17-30°C. In September 2021, Gujarat state was under the influence of the northwest monsoon and received a total 788.61 mm of total rainfall recorded on 30th September 2021, slightly less than the long-term average of 1992-2020 which is 850 mm. The cities of Vapi and Surat received 2265 mm and 1561 mm of total rainfall, respectively as on 30th September 2021 (GSDMA, 2021).

3.3.2.2 Sampling locations

Surface water samples were collected from the upper, middle, and lower stretch of the rivers. Daman Ganga and Tapi River in the cities of Vapi and Surat in Gujarat were sampled in December 2020 and Daman Ganga, Tapi River, and Dumas Beach were sampled in September 2021 (Figure 3.3.1. and Figure 3.3.2).

3.3.3 Sample collection methods

Several methods exist for collecting surface water samples from rivers, some of which are addressed in the context of macro- and microplastic sampling in Section 3.4. In addition to taking the samples, it is important to record sampling coordinates, weather conditions, wind direction, or sampling time. It is also recommended to gain a thorough understanding of different sampling procedures prior to selecting the approach and undertaking the sampling. Surface water is typically sampled using nets, like manta or plankton nets, pumps, or as bulk water samples.

Sampling in December 2020 was conducted using 500 ml amber glass jars that were filled with surface water at each location. Prior to taking the sample, the pre-cleaned sample jars were rinsed with the surface water three times to help remove residual microplastic contamination.

The sampling campaign of September 2021 used 500 ml amber glass jars along with nylon meshes of 0.3 mm and 1 mm mesh size and a trawl net with 3 cm mesh size. A stainless-steel circular rod with a diameter of 43 cm was welded to a straight rod 1 meter in length to prepare nylon nets with different

Figure 3.3.2 Sampling campaign in September 2021 (monsoon). (a) and (b) represent sampling sites of the upper and lower stretch of Daman Ganga River. (c), (d) represents the upper and lower stretch of Tapi River and (e) represents sampling sites of Dumas Beach in Surat.

Source: Google Maps

mesh sizes (0.3 and 1 mm). Both nylon meshes were stitched around the circular steel rod, creating two nested nets each with a length of 1 m. One trawl net was prepared by using a metal rectangular frame with dimensions 0.67 m by 0.5 m. A 3 cm mesh size net was attached to it, to create a net with a length of 3 m. A long rope was attached to the corners of the frame which was used to deploy the net from a bridge. The nets were placed in the rivers for a specific duration in order to collect plastics (micro, macro) flowing in the rivers.

3.3.4 Sampling processing and analysis of microplastics

3.3.4.1 Quality Assurance

The samples were stored in an icebox until analysis in the laboratory. Sample and laboratory analysis must be subjected to quality control measures to avoid contamination. All glasswares were was properly cleaned and rinsed with deionised water, then dried in an oven before analysis. Lab coats and gloves were worn at all times. Procedural blanks were conducted for every 1 litre of river water sampled. Pre-filtered deionised (DI) water was used for the blanks.

3.3.4.2 Laboratory Analysis for Microplastics

Identification of microplastics is often performed using visual analysis followed by spectroscopic approaches, such as Fourier Transform Infrared (FTIR) and Raman analysis. Thermal analysis like Gas chromatography-mass spectroscopy (GC-MS) is also performed. The shape, size, and colour of observed microplastics can be determined visually using a stereomicroscope. Through visual identification of microplastics, there is a high risk of misidentification or misclassification since there may be an overestimation or underestimation (Lusher et al., 2020).

Microplastic in surface water samples were isolated for analysis using density separation, sieving with a 0.5 mm sieve, and vacuum filtration. The samples were vacuum filtered through a 5 m silicon filter paper for analysis with an optical microscope and FTIR (Spectrum 3 attached with Spotlight 200i microscope, Perkin Elmer, USA) spectroscopy. The microscopy technique was used to confirm the shape

Figure 3.3.3. Main categories of macroplastics found in the samples.

of microplastics found: fibre, fragment, pellet, etc. The spectroscopy technique was used to identify the polymer composition, using a reference spectra library to confirm. A thermo-analytical technique of Pyrolysis GC-MS (Agilent Technologies, USA) was also performed to confirm the type of microplastic through pyrolysis of the sample and analysing the decomposition products of the polymer. Samples for this approach were prepared by vacuum filtering surface water samples through glass fibre (1.6 m) filter papers. The samples were pyrolyzed at 700°C and the decomposition products were analysed.

3.3.5. Summary of Findings

Macro- and microplastics were sampled from the river water by deploying nets of 0.3 mm, 1 mm, and 3 cm mesh size. The nylon nets were deployed in the river water for 30 minutes where the 0.3 mm and 1 mm nets were deployed from the bank of the river and the 3 cm net was deployed from a bridge. Macroplastics collected by the nets were counted, categorised, and weighed. Some major macro-plastics found are depicted in Figure 3.3.3.

Microplastic concentrations were calculated by relating observed microplastic counts to the total volume of each water sample. The highest concentration of microplastics in Daman Ganga River was found in Silvassa (S2) with 6.99 pieces/L followed by the location just downstream of the Madhuban Dam just before Rakholi bridge (S1) with 4.35 pieces/L. As we go further downstream the river, at Daman city the concentrations of microplastics was found to be 1.71 pieces/L and 1.08 pieces/L for Jetty De Damão Grande (S3) and Nani Daman Jetty (S5) respectively. Similarly, in Tapi River it was seen that the concentration of microplastics were higher upstream at Bori Savar village (Located downstream of Ukai Dam) with 3.72 pieces/L (S6) and 2.48 pieces/L (S8). The concentration at Surat River Front (S9) was found to be 0.93 pieces/L. The samples collected from Dumas beach (present in Surat where Tapi River meets the sea) showed that the concentration of microplastics was higher near the Dariya Ganesh Temple (S10) with 1.39 pieces/L and the samples collected few hundred meters away from the temple (S11 and S12) were lower at 0.46 pieces/L each (Figure 3.3.4.).

Microplastics extracted from the water samples consisted of various shapes and colours. The dominant colour identified was white (46.20%),

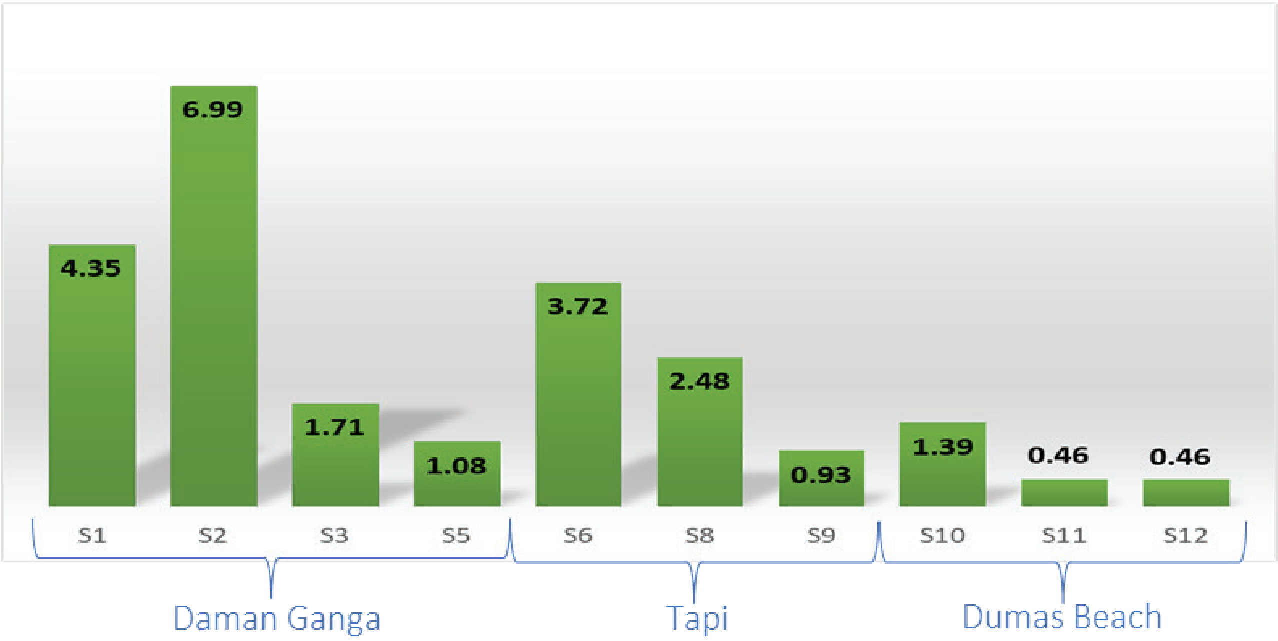


Figure 3.3.4. Concentration of microplastic particles quantified in surface water (pieces/L) from Daman Ganga and Tapi river, and Dumas beach.

followed by blue (19.80%), green (12.80%), yellow (10.30%), red (4.95%), black (2.89%), pink (1.65%), brown (0.82%), orange (0.41%), and grey (0.18%). The majority of microplastics were fragments (41.42%), followed by fibres (21.83%), films (17.40%), pellets (10.53%), and beads (8.82%).

Samples collected from the sampling campaigns were analysed using FTIR. During the sampling campaign of December 2020, the water samples collected from river Daman Ganga, included polypropylene microplastics from the upper stream of the river, polyamides from the middle stream, and traces of polyethylene and polyamides in the downstream. In the Tapi River, traces of cellulosic particles and polystyrene particles were found in the upper and middle streams, respectively. Samples from the September 2021 sampling campaign showed traces of low-density polyethylene (LDPE), polystyrene, and polypropylene in the upper stream of the Daman Ganga, and PET and HDPE in the lower stream. In Surat, water samples were collected from the Tapi River and Dumas Beach. In the upper stream of the Tapi River, PET microplastics were dominant, while PP and LDPE were detected in the lower stream. The water samples collected from Dumas Beach showed traces of microplastics composed of polymethyl methacrylate, polystyrene, and polypropylene.

Pyrolysis GC-MS was performed on selected samples from the September 2021 campaign. The Daman Ganga river sample contained polyethylene and polystyrene in the upper stream and polyamide and polyethylene in the lower stream. In the upper stream of river Tapi, polystyrene, ABS, and polypropylene microplastics were found, while PVC and ABS were found in the lower stream. PET, PC, and ABS microplastics were found on Dumas Beach.

3.4 Monitoring methods reviewed for the development of technical guidelines and harmonisation

3.4.1. Existing monitoring methods and current guidelines

Riverine plastic pollution is a problem that covers a broad spectrum of scales, across both space and time but also in relation to the specific attributes of the pollution. To facilitate effective monitoring, it is useful to subdivide into relevant categories. Here, we separate on the basis of both particle size (plastic litter and microplastic) and between plastic particles in motion in the river channel (hereafter, flux) and those that are stranded or stored in the river system (hereafter, accumulation). These represent meaningful groupings, based on the different approaches required to accurately measure them. It is, however, important to note that they are not well-defined, distinct, or fixed categories. The defining boundaries of terms such as 'plastic litter' and 'microplastic' have not yet been agreed upon internationally (Hartmann et al., 2019) and plastic particles may be transported, stored, or may fragment in river catchments across different spatial and temporal scales (Horton & Dixon, 2017; Lechthaler et al., 2020).

3.4.1.1. Plastic litter fluxes

Monitoring of plastic litter fluxes can be broadly subdivided into two main categories: observation-based approaches and physical interception-based approaches (van Emmerik & Schwarz, 2020). Observation-based approaches include visual observation, whereby human analysts survey and record visible plastic litter moving past a defined vantage point, as well as the use of unmanned aerial vehicles (UAVs) or cameras to record the surface of the river. The main advantage of these techniques is that they are quick and easy to undertake and require little infrastructure. On the other hand, they are only able to monitor visible plastic litter. Submerged plastics, especially in turbid rivers with low visibility, may not be detected. Physical interception-based approaches include the use of different forms of physical infrastructure to actively collect plastics and remove them from the river for quantification and characterisation. Examples include nets, booms, or trash racks. Of these, nets are the most widely used in the scientific literature. Some of these methods are able to monitor both floating and submerged litter, enabling more accurate flux estimates; however, they also require more equipment and personnel to deploy.

Several guidelines have been established, most commonly focusing on visual observation and the use of nets (e.g. Barnardo & Ribbink, 2020; González et al., 2016; Miliute-Plepiene et al., 2018; UNEP, 2020). Visual observation is proposed as a simple, low cost tool to establish general trends, whilst nets can also reveal sub-surface plastic litter flows and facilitate a mass-based estimate of riverine flux. It is also recommended to combine both approaches in a monitoring programme to obtain a better representation of plastic litter fluxes (e.g. Barnardo & Ribbink, 2020). Visual observation may utilise citizen science as an opportunity to obtain larger datasets with greater spatial and temporal resolution (Kiessling et al., 2021; van Emmerik et al., 2020).

3.4.1.2. Accumulation of plastic litter

Plastic litter may become temporarily stranded in riverine sediments and vegetation. Understanding this process is important as it may help to assess flushes of plastic associated with high flow events. These stores may also represent legacy sources of plastic in the future, even if active inputs to the river have been prevented. Riverbank environments, such as river beaches, can be monitored following an adapted OSPAR approach (OSPAR Commission, 2010; UNEP, 2020; van Emmerik et al., 2020). This comprises recording plastic litter along a transect or within a defined area. This may be suitable for monitoring visible plastic, but guidelines should also be developed to measure buried plastics – especially in floodplain systems.

Barnardo & Ribbink (2020) also set out guidelines for monitoring plastic litter in mangrove environments, detailing two techniques: a single stock survey and repeated monitoring based on total clearance and measurement of the rate of re-accumulation. These approaches may also be applicable for monitoring the accumulation of plastic litter in riparian vegetation, with some adaptations related to the hydrological setting. Monitoring of vegetation may be important in some rivers, as they may represent zones of significant accumulation that could be targeted in remediation efforts.

3.4.1.3. Microplastic fluxes

Fluxes of microplastic are typically extrapolated from analysis of the microplastic content of river water samples. This sampling can be approached in two main ways: bulk water sampling and the use of nets (AMAP, 2021; Bai et al., 2022; UNEP, 2020). Bulk water sampling requires a pump and often a series of sieves or nets to extract water from the river and volume reduce the sample on site (UNEP, 2020). Depending on the parameters of volume reduction (e.g., mesh size used) this technique can be used to measure small microplastics. Nets achieve volume reduction in-situ, and thus require less infrastructure to deploy. Due to the duration of deployment in the river, mesh sizes used for nets are typically around 300 m. Finer meshes may become quickly clogged with suspended material. Nets can be deployed from bridges, boats, or cranes, or by hand in wadable rivers (UNEP, 2020). They concentrate the suspended material which can then be retrieved from the nets for analysis. Careful contamination control measures should be set in place during the sampling, such as wearing natural fibre clothing, avoiding plastic where possible and documenting its use where not possible, and thorough rinsing of sampling apparatus with filtered water prior to taking each sample. Taking field blanks is advised (AMAP, 2021).

3.4.1.4. Microplastic accumulation

Thus far, the most common approach to estimate accumulations of microplastic in river catchments is to analyse sediment samples from the riverbed. Microplastic accumulate in bed sediments and often present relatively high concentrations compared to other riverine or marine settings (Hurley et al., 2018). No standard methodology yet exists for monitoring riverine sediments (AMAP, 2021; UNEP, 2020); however, current guidelines describe core or grab sampling as the most common approaches.

Microplastic may also accumulate in different parts of the river system, including in the bank or floodplain zone or in vegetation. These areas have received less attention thus far, and as such there are no current specific standardised or harmonised guidelines for undertaking this sampling. (González et al., 2016) describe some options for riverbanks, including taking sediment cores or monoliths. Further work is needed to test and recommend a harmonised approach.

3.4.2. Adapting to local conditions

River environments are highly diverse, globally. They can vary widely with regard to their hydrology and geomorphology and in response to local geology, climate, and degree of anthropogenic modification. As such, there is no single representative river, and methods that are developed to be optimal in one catchment may be entirely unfeasible in another. This variability does not only occur across large spatial scales but is also relevant within small regions and even within single catchments. This can be observed within India, where the geography varies significantly (e.g. from north to south) and which plays host to several large rivers that span different environmental settings (e.g. from the mountains to the coast). It is essential that local conditions in each monitoring location are taken into consideration when selecting methods and designing monitoring programmes. This includes, for example, the channel morphology (channel width and depth, riverbank morphology, occurrence of anastomosing/braided channels) or hydrological regime (discharge and/or flow velocity). For these reasons, harmonisation of methods is more relevant than standardisation, based on the adaptations that are necessary to tailor methods to the specific environmental context.

3.4.3. Towards harmonisation

Harmonisation refers to the collection and reporting of data in a way that facilitates comparability between different studies and different geographical contexts. To achieve this, it is important to undertake quality assurance and quality control (QA/QC) procedures during sampling and analysis to ensure accuracy and verify what a measurement represents. This could include the use of reference materials or tools to validate measurements or the inclusion of blank samples in microplastic analysis. Methods for measuring plastic litter in rivers are yet to be fully validated, and further methods testing is also required to establish thresholds or limits of the methods. Standardised methods may not be suitable for all river environments, but specific aspects of methods should be standardised where possible. For example, agreeing on the defining boundaries for plastic litter categories or standardising the attributes of nets used in sampling plastic litter and microplastic. Finally, data reporting should follow a standardised form that allows for comparability with other datasets, whilst also retaining a sufficient level of detail to characterise, for example, specific local sources of plastic.

3.5 Recommended monitoring programme for litter and microplastics for selected catchments

3.5.1. Opportunities and challenges in the selected catchments

As addressed in Section 3.4.2, it is important to consider the environmental context when designing monitoring programmes. The Tapi river is 724 km long and the total catchment area represents 2% of the land area of the Indian peninsula (65,145 km^2) (Kale & Hire, 2004). The Daman Ganga is smaller, with a length of 140 km and draining a catchment of 2300 km^2 (Anwat et al., 2021). The average annual rainfall for the Tapi and Daman Ganga are 848.9 and 2144.5 mm, respectively (Central Water Commission, 2020). Both catchments play host to dams. The role of dams in capturing plastic litter and microplastic is not yet well-understood (Liro et al., 2020; Watkins et al., 2019). This could form the basis of an investigation to better understand their influence but, in the interest of establishing flux estimates to the ocean, monitoring should be confined to the section downstream of the lowermost dam; namely, the Ukai dam in the Tapi River and the Madhuban dam in the Daman Ganga River. These sections also host the main cities within both catchments: the city of Surat in the downstream Tapi and the city of Daman in the downstream Daman Ganga. This helps to focus monitoring within a more practical spatial extent.

Both catchments are heavily influenced by the summer monsoon, where 90% and 94% of the annual precipitation occurs between June and September in the Tapi and Daman Ganga, respectively (Anwat et al., 2021; Kale & Hire, 2004). Besides a few exceptional flood events, the majority of high flows are contained within the channel banks (Kale & Hire, 2004). Flows during the rest of the year are negligible, comparatively. Monitoring should investigate the seasonal differences in plastic flux to help better tailor measures to reduce plastic releases. Measurements of plastic accumulation should focus on the exposed riverbed that is revealed during the dry season and tracking how much of the temporarily stored (micro)plastic is transported with high flow events during the monsoon months.

A key challenge associated with the selected catchment relates to their physical dimension: the rivers are very wide in their downstream sections. In both rivers, the channels range from approximately 200 m to 1 km in width. This can make it difficult to take samples or measurements that are representative of the full river cross-section at a given site. In addition, the suspended sediment load of both rivers is high, resulting in highly turbid waters with low visibility. This creates challenges for monitoring that either relies on visual observation or aims to concentrate suspended particles to capture microplastic. Finally, there are few sites on both rivers that represent suitable locations for undertaking representing sampling. In many cases, the bridges crossing the rivers are very high and both rivers exhibit minimal boat traffic (and therefore availability of boats), except in the estuarine zone. These challenges must be considered when establishing effective monitoring programmes.

3.5.2. Recommendations for monitoring plastic litter and microplastics

3.5.2.1. Recommendations for monitoring plastic litter fluxes

The selected catchments present some challenges to the current approaches for measuring plastic litter fluxes: the rivers are very wide, bridges tend to be high, and there is a low availability of boats. To overcome these, it is recommended to utilise multiple methods in combination. Visual observation should be conducted routinely and may take advantage of opportunities to utilise citizen science by providing standardised protocols and data collection forms (Kiessling et al., 2021; van Emmerik et al., 2020). The most suitable bridges for visual observation should be mapped: the lowest bridges that also offer a pedestrian area separated from road traffic. It may be necessary to set a higher lower size limit for accurately detecting plastic items than used in other studies. This somewhat reduces the comparability of the data, but it is still useful to establish broad spatial and temporal trends. Reference items could be used to validate detection limits. Visual observation should be conducted at several points across the river width, to establish more accurate flux estimates of floating litter. This can be done by dividing the river into sections and observing them sequentially (van Emmerik et al., 2018).

Nets should also be used in parallel. This would capture the floating and non-floating component and increase the accuracy of flux estimates. The nets could be deployed from lower bridges where possible, or from boats in the downstream zone. During the dry season or in upstream tributaries, it may also be possible to wade into the river to deploy nets. This has been observed in the selected catchments as part of local fishing activities. The net mesh size should be set to 2.5 cm, to conform with the most commonly used size boundary for plastic litter (Miliute-Plepiene et al., 2018; UNEP, 2020).

Monitoring of plastic litter fluxes should aim to establish spatial and temporal differences. Monitoring close to river mouths can be useful to estimate release to the ocean from different catchments, whilst monitoring through the year can establish seasonal variability. The visual observation results should be used to determine the location of net deployment(s) at a given monitoring location, to help obtain representative samples.

3.5.2.2. Recommendations for monitoring plastic litter accumulation

As described above, the Tapi and Daman Ganga rivers exhibit varying degrees of riverbed exposure in response to changing water levels. pl[= Monitoring should follow the adapted OSPAR method to survey visible plastic litter (UNEP, 2020). It is also recommended to investigate the inputs to the river environment during the dry season: stranding of plastic transported in the river *versus* dumping of litter at the riverbank. This would help to identify optimal pollution reduction measures.

3.5.2.3. Recommendations for monitoring microplastic fluxes

Large volumes of river water are needed to obtain a representative microplastic sample (Koelmans et al., 2019). This is easier to collect when using nets as less infrastructure is needed and the water does not need to be extracted from the river. Bulk water sampling may also be hindered by the high suspended sediment load in the selected catchments. Nets could be deployed in a similar way as described for litter above but with a lower mesh size. This has already been trialled in the INOPOL project. The mesh size sets a lower size limit of around 300 m, but this is considered suitable for routine monitoring purposes (AMAP, 2021). The duration of deployment should allow a sufficient volume of water to pass through the nets but limit the potential for clogging with suspended material.

3.5.2.4. Recommendations for monitoring microplastic accumulation

Microplastic accumulation should be monitored by taking riverbed sediment samples. This should include sampling of both submerged and exposed portions, to better understand the accumulation of microplastic in the active channel and the availability of microplastic for remobilisation during high flow conditions. The sampling method should be comparable for both sample types to ensure comparability: i.e. using only corers or only grab samplers. Monitoring of sediments should be performed prior to and following the monsoon season, to establish a seasonal pattern of accumulation in rivers.

It may also be of interest to monitor the accumulation of microplastic in the sediments of the Ukai and Madhuban dams to investigate their potential role in interrupting the flux of microplastic downstream (UNEP, 2020).

Chapter 4

HOTSPOT ASSESSMENT AND MODELLING OUTCOME

4.1 Review of local/state level waste generation data to determine 'hotspots' for litter and plastic waste in selected catchments

KEY POINTS

- Gujarat, recognised as one of the most industrialised states, has significant presence of pharmaceutical (33% share in drug manufacturing in India), chemical (53% of total chemical industries in India), refining and petrochemical industries, as well as ceramics, textiles (25% share in total production of textiles in India), automobile factories.
- The increase in numerous industrial establishments has resulted in increase of many hazardous industrial pollutants. The state accounts for 28% hazardous waste generated in the country.
- The hazardous waste management has been a critical issue that has gained worldwide relevance. The negative consequences of indiscriminate hazardous waste disposal have resulted in an ecological disaster.
- Cities like Surat and Vapi in Gujarat are among the top cities in the state hosting many industries which contribute to waste generation thereby polluting the rivers Tapi and Daman Ganga respectively.

4.1.1 Assessment of waste generation in the state of Gujarat

Gujarat accounts for approximately 28% of hazardous waste generation in India from the 7751 hazardous waste generation unit. In addition, the state generates 10,200 MT of municipal solid waste (MSW) and the industrial hazardous wastes accounts of 1,792,789 MTA per day in Gujarat, out of which 25.5% is treated, 16.7% is sent to landfills, while 57.8% is improperly disposed of (Ahuja & Abda, 2015). Also, the domestic sewage generation in the state accounts for 5013 MLD (CPCB, 2022).

Gujarat contributes to 12% of total plastic waste generated in India (CPCB, 2022). As of 2019-20, the plastic waste generation in the state was estimated to be approximately 408201.08 TPA. Within the Gujarat state, 1049 units (1027 plastic manufacturing/ recycling units, 12 compostable plastic units and 10 multi-layered plastic units) are registered. There are no unregistered plastic manufacturers/recyclers in the State (CPCB, 2021).The cities of Surat and Vapi were considered as hotspots because these cities host many industries and large population producing substantial quantity of waste that affects Tapi and Daman Ganga rivers, respectively. Over 41,300 medium and small industries are in operation in Surat and 1500 industries in Vapi. About 70 percent of the industries produces a variety of chemicals like dyes, pigments, pesticides, and pharmaceuticals while

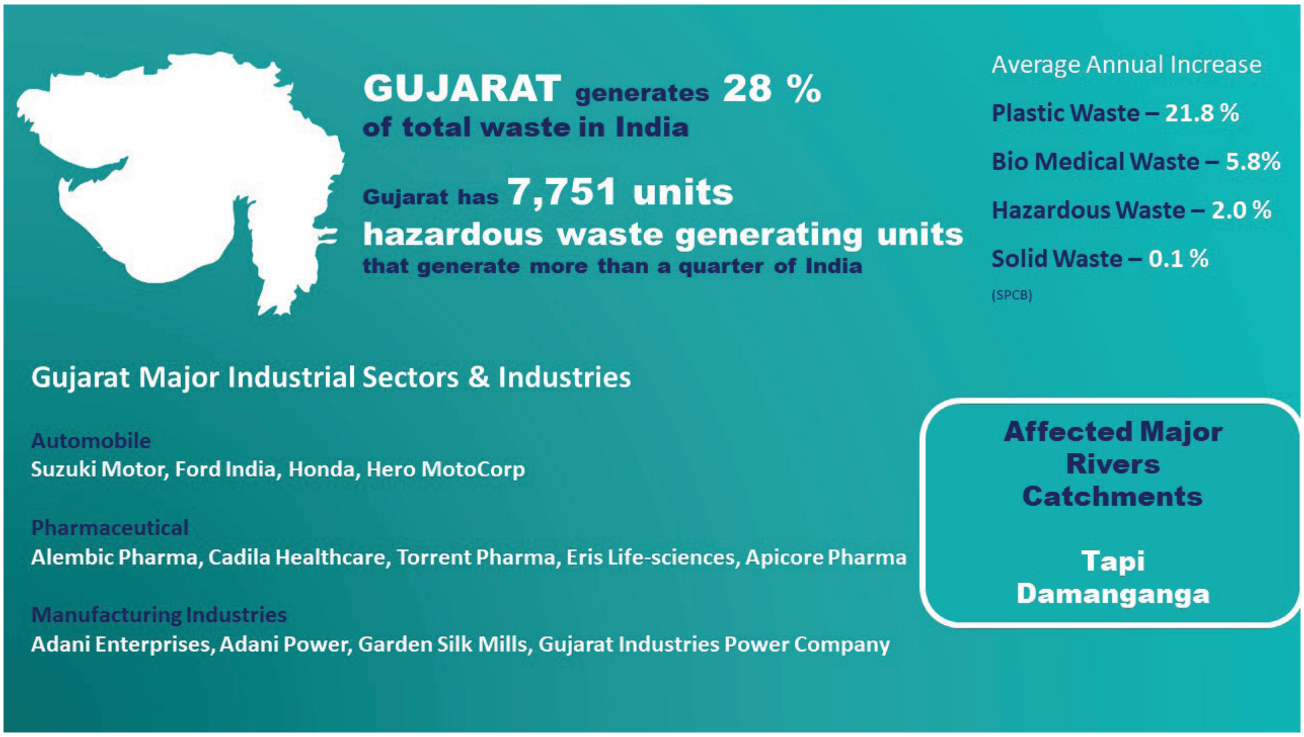


Figure 4.1.1. Amount and type of wastes generated from some major industries affecting the river catchments in Gujarat.

Source: State Pollution Control Board (SPCB), Gujarat

the remaining 30 percent comprises paper-mills, plastic, packaging, engineering and other small-scale industries.

4.1.2 Water pollution in Tapi River, Surat

Tapi River flows through Madhya Pradesh, Maharashtra and Gujarat states and ends up in Gulf of Khambat. The industrial city of Surat is a well-known textile hub of Gujarat and is hosting several industries such as textiles mills, fertilizers industries, petrochemical industries, chemical plants, diamond processing units etc. (Varghese, 2011). As a result, different kinds of effluents pollute Tapi. The city of Surat generates around 1800 tons of municipal solid waste in a day (Bhakkad, 2019).

The Tapi River basin lies between east longitudes of 72º 38’ to 78º 17’ and north latitudes of 20º 5’ to 22º 3’. Many ongoing projects are being implemented in the river basin. Currently there are 28 major and medium irrigation schemes completed and 2 projects are in construction in the form of reservoirs or weirs in the Tapi catchment. The important projects in Tapi Basin are Hatnur Dam (Maharashtra), Kakrapar Weir (Gujarat), Ukai Dam (Gujarat), Girna Dam (Maharashtra) and Dahigam Weir (Maharashtra) (CWC, n.d.). The construction of weirs has progressively changed the water body into a more lentic, standing water body and has resulted in the accumulation of pollution load from within the city.

4.1.2.1 Industrial effluents in Tapi River

Release of untreated water and waste into Tapi by over 150 industrial units present in Surat is a major source of pollution in the river water. Around 87 villages located in the vicinity of the upper and lower stream of the river release sewage which only worsens the situation. Additionally, dumping the effluents from the giant industrial units and industrial complexes further worsens the situation.

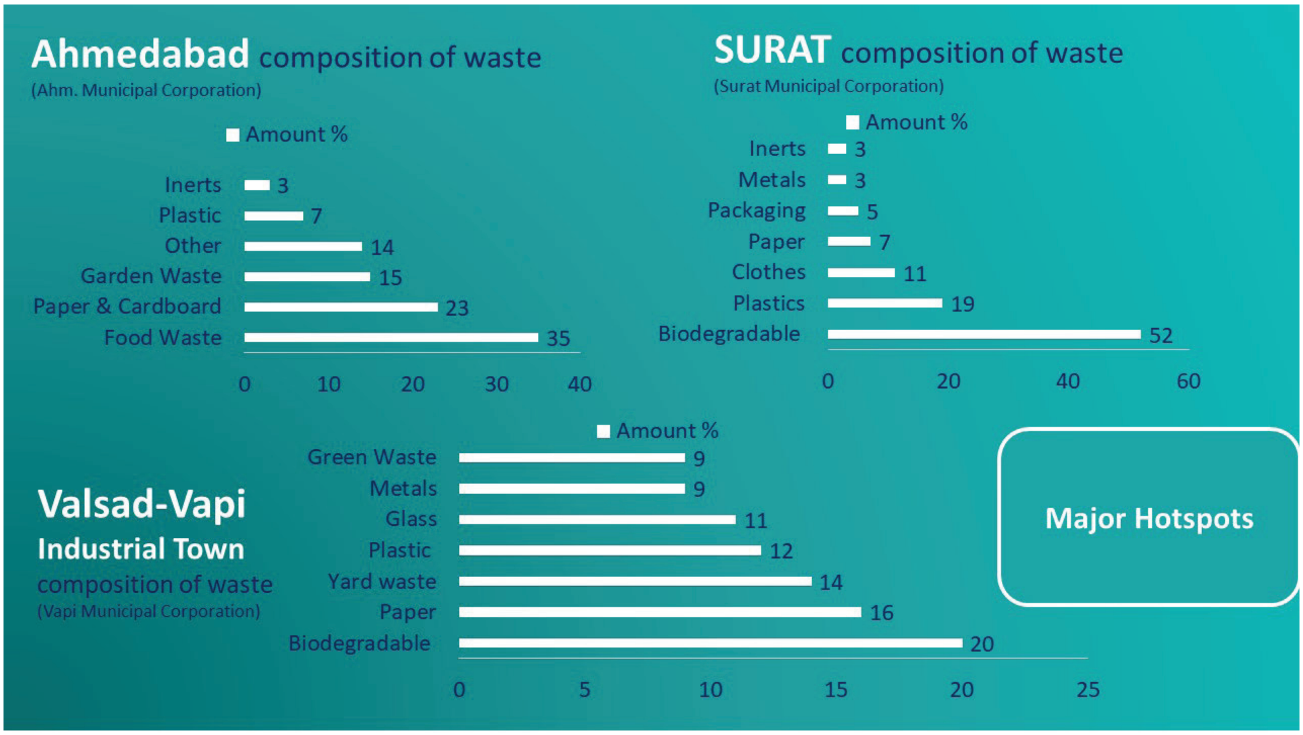


Figure 4.1.2. Categories of waste in Gujarat's major cities.

Source: Municipal corporations of Ahmedabad, Surat, Vapi & State Pollution control board (SPCB), Gujarat

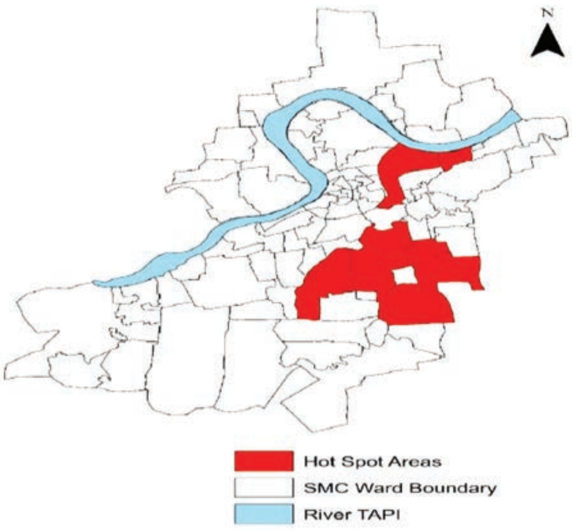


Figure 4.1.3. Hotspots of MSW burning in Surat by wards. (High consumption of polluting fuel)

Source: (GPCB SMC, 2021)

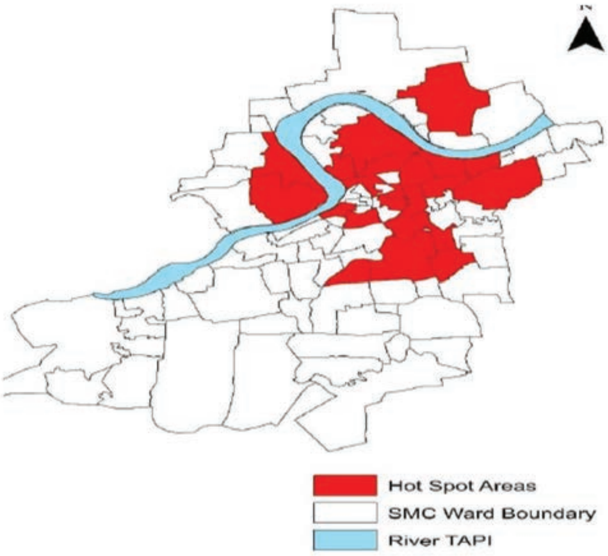


Figure 4.1.4. Hotspots of MSW burning in Surat by wards. (High waste burning)

Source: (GPCB SMC, 2021)

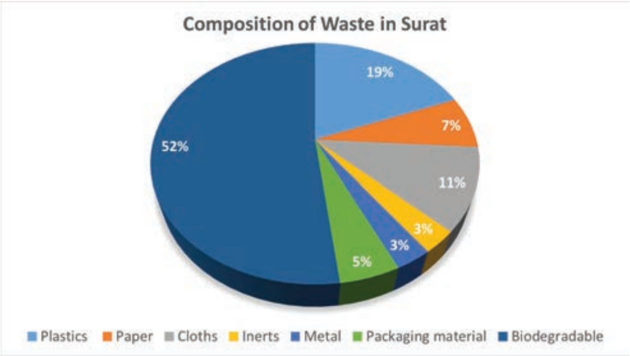


Figure 4.1.5. Categories of municipal solid waste (MSW) in Surat (in TPD)

Source: (Biswas et. al, 2021)

4.1.2.2 Municipal Solid Waste in Tapi River

Surat generates a total of 1838 TPD of municipal solid wastes (excluding C&D waste and inerts) (Biswas et. al, 2021). The category of these solid wastes along with the quantity generated (in TPD) is depicted on Figure 4.1.5. above.

For the produced waste, the total treatment and disposal capacity involves the following (GPCB, 2019);

- 50 TPD bio methanation at Agricultural produce market committee (APMC) market
- 700 TPD composting at Khajod Disposal site
- 10 TPD decentralised plant for onsite treatment of solid waste
- 500 TPD RDF unit at Khajod disposal site
- 20 TPD Plastic treatment unit at Bhatar
- 300 TPD Construction and demolition (C&D) treatment unit at Kosad
- 100 TPD industrial solid waste plant is under tendering state
- 0.7 TPD plant is operational since 2003 (bio-medical plant)

4.1.2.3 Industrial Solid Waste in Surat

In Surat, the industrial solid waste, which is generally produced during the manufacturing of products, agricultural production or during the extraction of natural resources is a one the major source of pollution in Tapi River (Dubey & Ujjania, 2013) . The production of 40% of national man-made fabric and 28% of national man-made fibre is performed in Surat. The total plastic produced from industries in Surat is around 150000 kgs out of which 19% are considered waste. The textile industries of Surat generate around 1.2 lakhs of bags which can reach the Tapi River through direct disposal or through natural causes like wind or rain mobilization. Other non-hazardous solid wastes from industries include paper (7%), clothes (11%), packaging material (5%) and metals (3%).

4.1.3 Water pollution in Daman Ganga River, Vapi

The Daman Ganga River starts from the Sahyadri hill ranges and flows a total distance of about 131.30 km to its final destination into the Arabian Sea at Daman (CWC, n.d.).

The major sources of pollution in river Daman Ganga are: Industrial effluents, domestic sewage, solid waste and open drains discharging into the river.

4.1.3.1 Industrial effluents in Daman Ganga River

The major industrial effluents discharged into the river are from the Common Effluent Treatment Plant (CETP) of the GIDC, Vapi and Gujarat Heavy

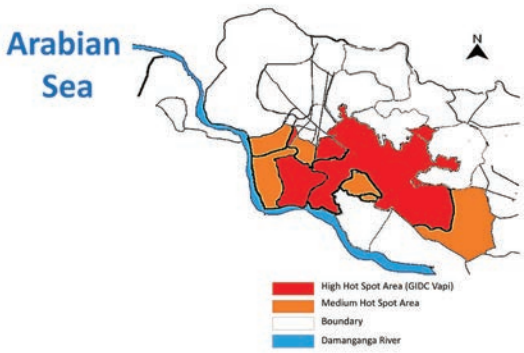


Figure 4.1.6. Polluted areas of Vapi

(Source: Adapted based on information from (GIDC, n.d.))

Table 4.1.1. Classification of discharge drains in Daman Ganga.(Daman Ganga, 2019)

Drain Discharge [Notation by –UTA D&D]	Strength of Effluent/Wastewater
D-01 to D-10, D-12, D-13, D-14 and D-16	Low strength wastewater
D-20, D-21 and D-22	Medium strength wastewater
D-17 and D-19	Seasonal drains
D-18	Removed
D-11A, D-11B and D-15	High strength wastewater

Chemicals Limited (GHCL), Bhilad. The treated effluents from CETP and GHCL is approximately 55-60 MLD and 2.5 MLD flow per day, respectively. The water in the river downstream of CETP (Vapi discharge location), is highly coloured, indicating severe pollution, which persists till the river meets the Arabian Sea (NGT Report, 2019).

4.1.3.2 Open Drain Discharges in Daman Ganga River

There are about 23 drains discharging effluents from Madhuban Dam to Arabian Sea, which are categorised as low, medium & high strength wastewater based on their characteristics (Daman Ganga, 2019).

4.1.3.3 Municipal Solid Waste in Daman Ganga River

MSW accounts for 8.50 TPD from notified area authority, Vapi and 50 TPD of MSW waste from Vapi Nagar Palika and approximately 65-70% managed properly and treated. In addition, the area has 38 health care facilities authorised by SPCB/PCCs which produce 250 Kg/day bio medical waste which is treated (Daman Ganga, 2019).

4.1.3.4 Domestic Sewage Waste in Daman Ganga

Presently, about 21 MLD of domestic sewage is being generated in the Vapi Nagar Palika area (NGT Report, 2020). Domestic wastewater from catchment areas is discharged into the Daman Ganga River. The sources of this domestic wastewater are mainly from towns/cities and settlements along the riverbanks. Most of the wastewater generated from towns is discharged into the river without proper treatment. In the river segment downstream of Vapi, the river receives 3 domestic wastewater drains after discharge point of Distillery (Daman) till Moti-Daman Jetty (Daman) which causes further deterioration of the river water.

4.1.3.5 Industrial Solid Waste in Vapi

The town of Vapi (population 71,000) marks the southern end of India's "Golden Corridor", a 400km belt of industrial estates in the state of Gujarat. Vapi accommodates about 1382 industrial units out of which 800 units are operational. The present disposal of industrial solid waste accounts for 4.02 lakhs MT (GCPC-ENVIS, n.d.) which comes from industries like Plastics, Paper & Packaging, Textiles, Leather and Rubber, Electrical and Electronic Industries etc.

4.2 Hydrodynamic modelling background

India ranks among the top five countries emitting the most plastics to the ocean and aquatic ecosystems, according to recent modelling studies (Borrelle et al., 2020; Jambeck et al., 2015; Lebreton & Andrady, 2019; Meijer et al., 2021). One of the main limitations of these studies is the lack of country-specific and catchment-scale data on waste generation rate, plastic content in waste, mobilization, and transport rate over land and along the aquatic continuum. In fact, modelers have provided elegant workaround solutions to fill those data gaps. The plastic content in municipal waste in India, for example, has been estimated from the average of low-middle income countries of South Asia (e.g., Borrelle et al., 2020; Lebreton & Andrady, 2019). Nevertheless, two major global waste generation datasets covering most of the World's countries, as well as selected large cities, e.g., the Waste Atlas and the World Bank dataset, are available and have been widely used in plastic modelling studies (Hoornweg & Bhada-Tata, 2012; Waste Atlas, 2022). While the World Bank dataset is no longer updated, the World Atlas dataset seems to be updated through contributions of scientists from different countries and published data. Hence there is no readily available dataset covering the entire Tapi or Daman Ganga catchments. In this section, we have provided an overview of the data available for the two catchments at the best spatial resolution possible and describe how these can be aggregated for modelling river transport of plastic waste from land to sea.

The data used to generate a homogeneous time series of plastic waste generation rates in each Urban Local Body (ULB) in both studied catchments included reports from Indian State Pollution Control Boards (e.g., MPCB, 2021; MPPCB, 2021), Central Pollution Control Board (CPCB; CPCB, 2021) as well as Surat and Vapi metropolitan regions (Surat Municipal Corporation, 2021; Vapi Municipality, 2020). The most complete dataset covering 8 out of 14, and 64 out of 91 ULBs in Daman Ganga and Tapi catchments, respectively, was from the Maharashtra Pollution Control Board in 2019 and 2020 (Figure 4.2.1. MPCB, 2020, 2021). The latter included information on waste collection and segregation rates which have been used to determine the fraction of mismanaged waste. In brief, the uncollected as well as the un-segregated but collected waste was considered as mismanaged and thus available for mobilization and transport into the natural

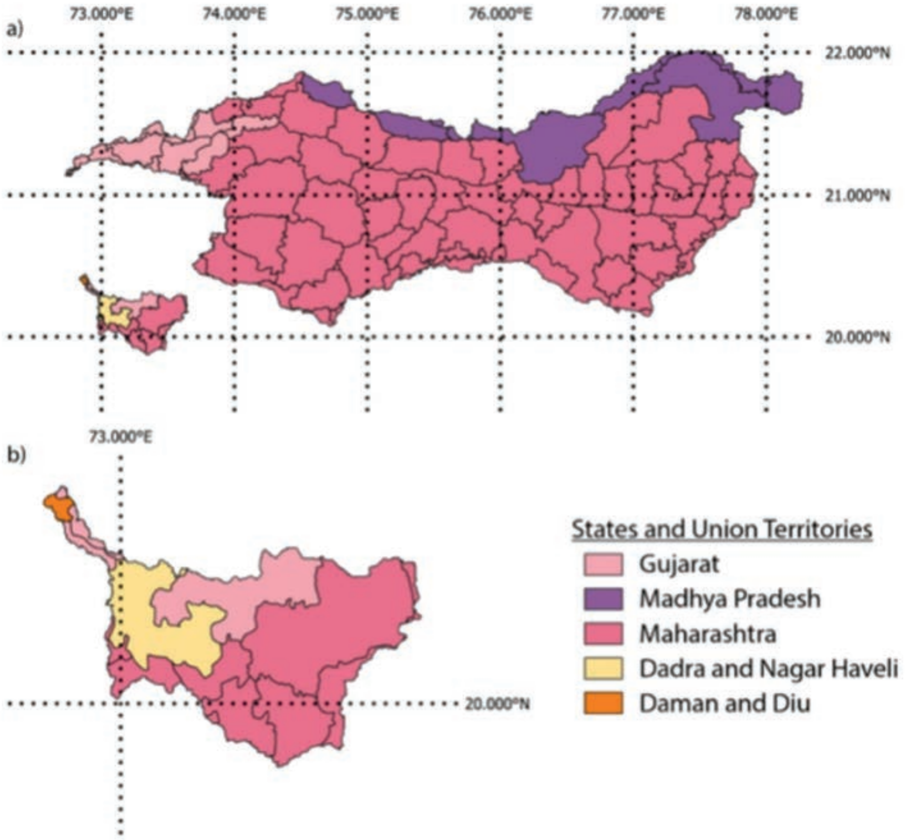


Figure 4.2.1. Catchment maps of Tapi (a) and Daman Ganga (b) showing ULB extents as well as States and Union Territories.

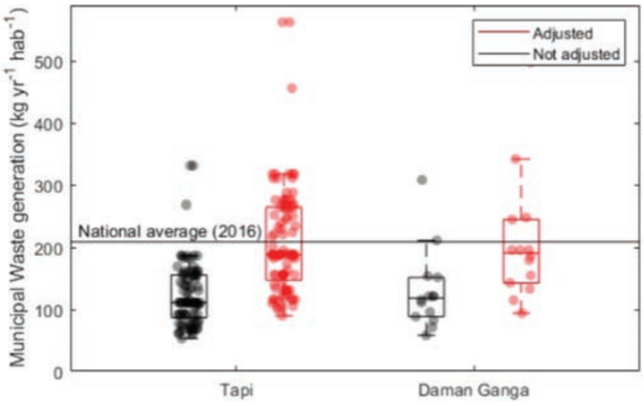


Figure 4.2.2. Boxplots of municipal waste generation rate in Tapi and Daman Ganga catchments. Black and red boxes are the unscaled (not adjusted) and scaled (adjusted) data, respectively, see text for details. Each dot represents one ULB

(*Source*: see text).

environment. Other datasets are from Gujarat, Maharashtra and Madhya Pradesh Pollution Control Boards, as well as from Surat and Vapi municipal council reports from either 2020 or 2021 have been used to complement the 2020 Maharashtra dataset. In the latter sources, information on collection and segregation rates were not systematically available. Hence, information from local waste collection system capacity has been gathered or when missing, the average of the other ULBs has been used.

When comparing the aggregated dataset for Tapi and Daman Ganga catchments to the 2016 national average reported by Kaza et al. (2018), it appears likely that the collated dataset includes significant underestimations. In fact, more than 95% of the ULBs in both catchments have waste generation rates that are significantly lower compared to the 2016 national average (Figure 4.2.2.). In order to work with realistic waste quantities, a second version of the dataset was created where the waste generation rates were bias corrected using the differences in the means. This second dataset is hereafter referred to as the "scaled" or "adjusted" dataset. Since the added waste was unaccounted in the state or municipal reports, it was assumed that it was mismanaged. Hence, the proportion of mismanaged waste for the scaled dataset is much larger than for the unscaled one (Figure 4.2.3.). Nevertheless, only a small fraction of the ULBs in each catchment are associated with proportion of mismanaged waste that are equal or higher than the value reported by Kaza et al. (2018) for India in 2016. Hence, the scaled dataset can still be regarded as conservative and/or representing a significant improvement in waste management.

Regarding the plastic content in waste, the CPCB as well as the Madhya Pradesh Pollution Control Board reported plastic waste generation rate at the State and municipal level, respectively (CPCB, 2019, 2021; MPPCB, 2019, 2021). For simplicity and because of the lack of spatial coverage, we considered an average of 7% of plastic in total solid waste which is in agreement with the above-mentioned sources as well as the average of low-middle income countries of South Asia (e.g., Borrelle et al., 2020; Lebreton & Andrady, 2019).

Over time, plastic production and waste generation has increased exponentially (Plastics Europe, 2013). When plastic waste is mismanaged, it is considered to be available for mobilization and transport from land to sea through wind, surface runoff and

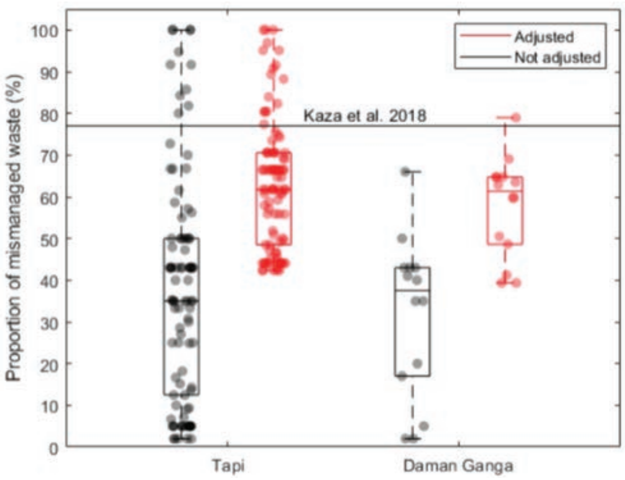


Figure 4.2.3. Boxplots of proportion of mismanaged waste in Tapi and Daman Ganga catchments. Black and red boxes are the unscaled (not adjusted) and scaled (adjusted) data, respectively, see text for details. Each dot represents one ULB

(*Source*: see text).

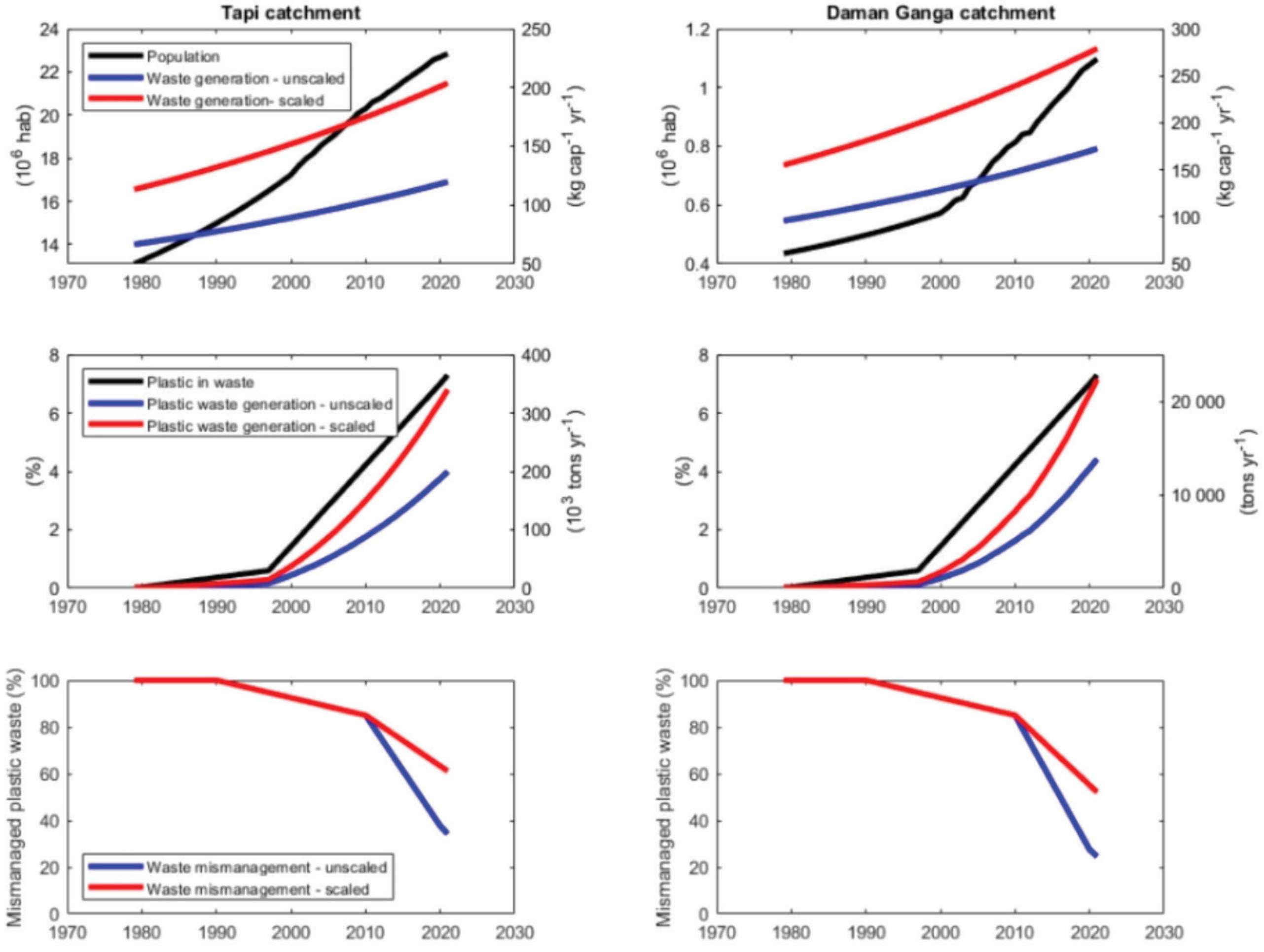


Figure 4.2.4. Population, waste generation (scaled and unscaled; top panels), proportion of plastic in waste and plastic waste generation (scaled and unscaled; middle panels), as well as waste mismanagement (scaled and unscaled; bottom panels) over 1980-2020 for Tapi (left) and Daman Ganga (right) catchments.

riverine transport (Meijer et al., 2021). However, large proportions of mismanaged waste remain trapped on land in illegal dump sites, in landfills of variable level of management as well as in the environment. In fact, Borrelle et al. (2020) estimated that 25% of mismanaged plastics in India reached the aquatic ecosystems, including lakes, rivers and sea, each year, leaving 75% behind in the terrestrial environment. Furthermore, only 0.4% of the mismanaged plastics in India have been estimated to reach the ocean each year, according to Meijer et al. (2021). Overall, the fate of mismanaged plastic waste is largely unknown over time. Hence, long-term accumulation of plastics in the environment must be included to fully appreciate the uncertainties in plastic exports to the sea through riverine transport. Remediation efforts targeted on accumulated mismanaged plastics in the past can have a large influence on the present and future plastic exports to sea, in addition to synchronous improvement in present and future plastic waste management.

Despite the lack of data on plastic and total waste in India before 2010, some information can be used to estimate the timeseries data on waste generation. Apart from the rise in population, as India's living standards rose, its waste generation increased at

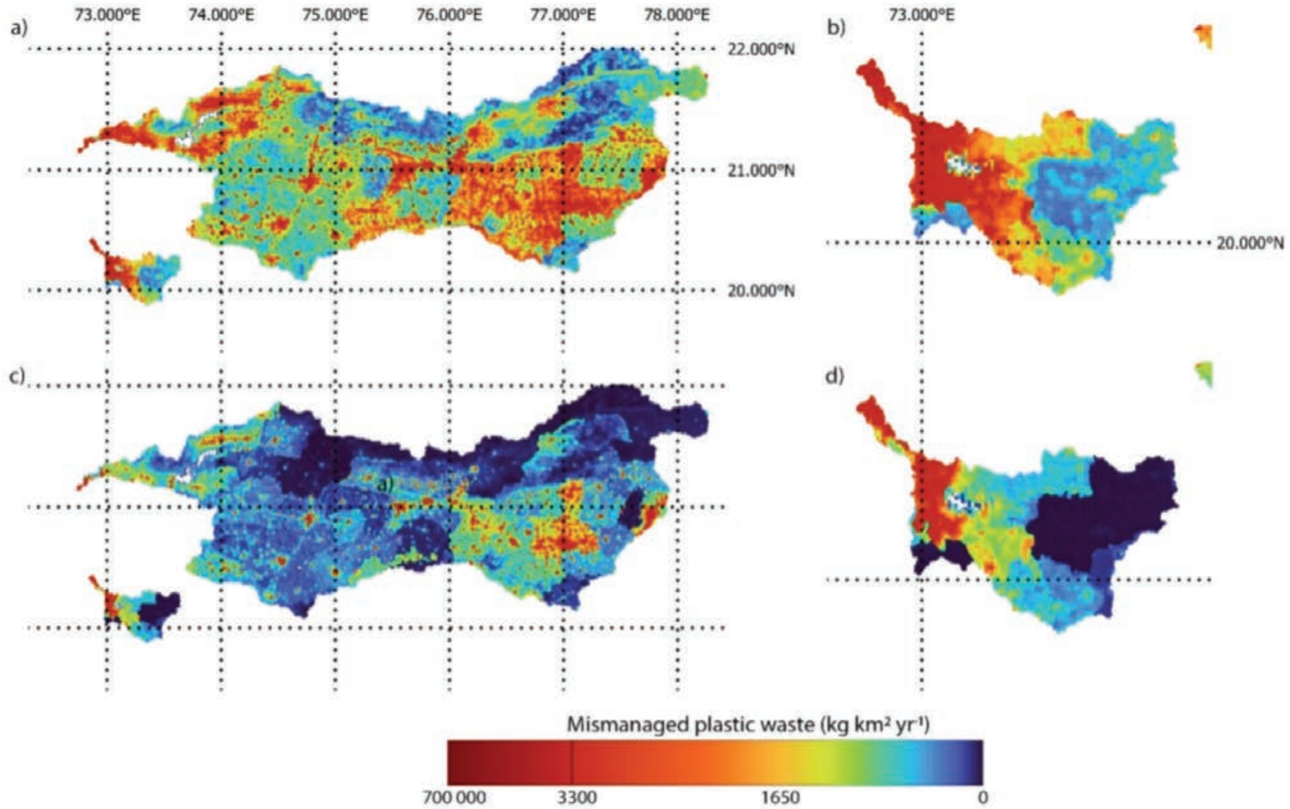


Figure 4.2.5. Catchment maps of Tapi and Daman Ganga (a and c) as well as Daman Ganga close-up (b and d) showing estimated mismanaged plastic waste in 2020 calculated from population density maps (WorldPop, & Bondarenko, Maksym, 2020), waste generation rate and proportion of mismanaged waste, as shown in Figs 4.2.2 and 4.2.3. Panels a) and b) display the scaled mismanaged waste while panels c) and d) display the unscaled mismanaged waste. Note that the colorbar scale is not linear above 3300 kg km^2 yr^{-1}.

a rate of 14% every decade (S. Kumar et al., 2017). Population over 1980-1999 was assumed to follow an annual 1.5% growth while from 2000 onwards, population density maps, at 30 arc resolution (approximately 925 m in the studied catchments) were used to derive annual population counts in each catchment (WorldPop, & Bondarenko, Maksym, 2020). The plastic waste content in solid waste also changed drastically since the 1990's, since it was 0.6% of total waste in 1997 (CPCB, 1997) and reached 5-7% within the 2010's (CPCB, 2007, 2010). In parallel, state-level and nation-wide waste management policies were first introduced in the early 2000's (Kumar & Agrawal, 2020) which leads us to assume that waste management before 2000 was inefficient, and has improved since 2010 (Kumar & Agrawal, 2020).
To match with the various levels of plastic waste management in each ULB as shown in Figure 4.2.3., single mismanagement trajectories for each ULB were calculated from 2010 to 2020. All temporal trends are summarized in Figure 4.2.4. above.

Figure 4.2.5. shows the estimated mismanaged plastic waste in 2020 in both studied catchments. The fine spatial resolution of population density datasets highlights some hot spots of potential plastic emission. In practice, population density data allows us to redistribute the waste spatially within each ULB concentrating the waste in densely populated areas. Areas with the highest level of mismanaged plastic waste in Tapi catchment for both, unscaled and scaled datasets, include the upstream southeast Tapi sub-catchment with the city of Akola, cities in the center and southwest, e.g., Dhule, Jalgaon and Malegaon, as well as areas north and downstream of Ukai dam such as the large Surat

city (Figure 4.2.5. a and c). Within the Daman Ganga catchment, the highest mismanaged plastic waste values are mainly found downstream of Madhuban reservoir with the towns of Silvassa, Vapi and the city of Daman (Figure 4.2.5. b and d). In contrast, the north-east corner of the Tapi catchment display relatively low levels of mismanaged plastic waste, mostly corresponding with ULBs within Madhya Pradesh State. Within Daman Ganga catchment, the south-east corner is covered by the *Peint* ULB which has been reported to have a very low mismanagement rate of 2% and 39% in the unscaled and scaled dataset, respectively.

High levels of mismanaged plastic waste do not necessarily imply proportionally high levels of plastic waste exports because this link is governed by plastic waste mobilization and transport on land and along the aquatic continuum through rivers, lakes, and reservoirs. Quantification of plastic waste exports is thus not straightforward and include multiple sources of uncertainty. Below, we describe the main results of hydrological riverine modelling applied to plastic waste as well as the main uncertainties and some recommendations.

4.3 Hydrodynamic modelling results

4.3.1 Model description and setup

A hydrological catchment model was set up for Tapi and Daman Ganga, including a Macroplastic module to simulate the mobilization from riverbanks, transport in river water, attachment and detachment from riverbanks and river vegetation of plastic items. The model also includes the effect of tearing on plastic films (e.g., bags) or grinding on hard plastic. The catchment model is composed of two modules, the hydrology model PERSiST (Futter et al., 2014) which was coupled to the INCA-Macroplastics model (INCA-Macroplastics; under development). In brief, macroplastics are deposited on the riverbanks and can be entrained into the river current through dragging which is scaled to the river flow. Once in the river, macroplastics can hit the river bottom and get attached again, including to vegetation if river vegetation is present. If the dragging force reaches a given threshold, the items can be moved again. PERSiST model parameters include site-specific information on soil water and groundwater retention, evapotranspiration as well as river size, width, depth, slope, and catchment characteristics. INCA-Macroplastic model can take various types of plastic items which are associated with specific drag coefficient, e.g., a plastic bag will have a higher drag coefficient than a thin plastic plate making it more easily mobilizable. Other parameters include average item major length, area, weight for each macroplastic type as well as some tuning parameters to calibrate bank attachment, detachment, drag force threshold as well as tearing and grinding.

Daily time steps were used over 1979-2020 to be able to assess potential accumulation with time and long-term as well as seasonal dynamics of macroplastic transport and stores in Tapi and Daman Ganga rivers. The input data for PERSiST, i.e., daily air temperature and total precipitation, were downscaled over the entire catchment from the ERA5 gridded dataset (Hersbach et al., 2020). The input data for INCA-Macroplastics, i.e., daily plastic item inputs to riverbanks were calculated based on the aggregated waste dataset described above considering several alternatives for plastic emissions from land to riverbanks which are described below in details. Due to the lack of measured macroplastic counts over a variety of hydrological conditions to compare modeled results with, we could not perform any formal uncertainty analysis. Instead, the values of the most sensitive parameters were varied within ranges reported in the literature (or estimated from expert knowledge) to estimate uncertainty.

Both Tapi and Daman Ganga rivers experience a high degree of regulation with the presence of large reservoirs and some water abstraction mainly for irrigation purposes (Gupta et al., 2022; Figure 4.3.1.). This was a major limitation in developing skillful daily river flow simulations since data on

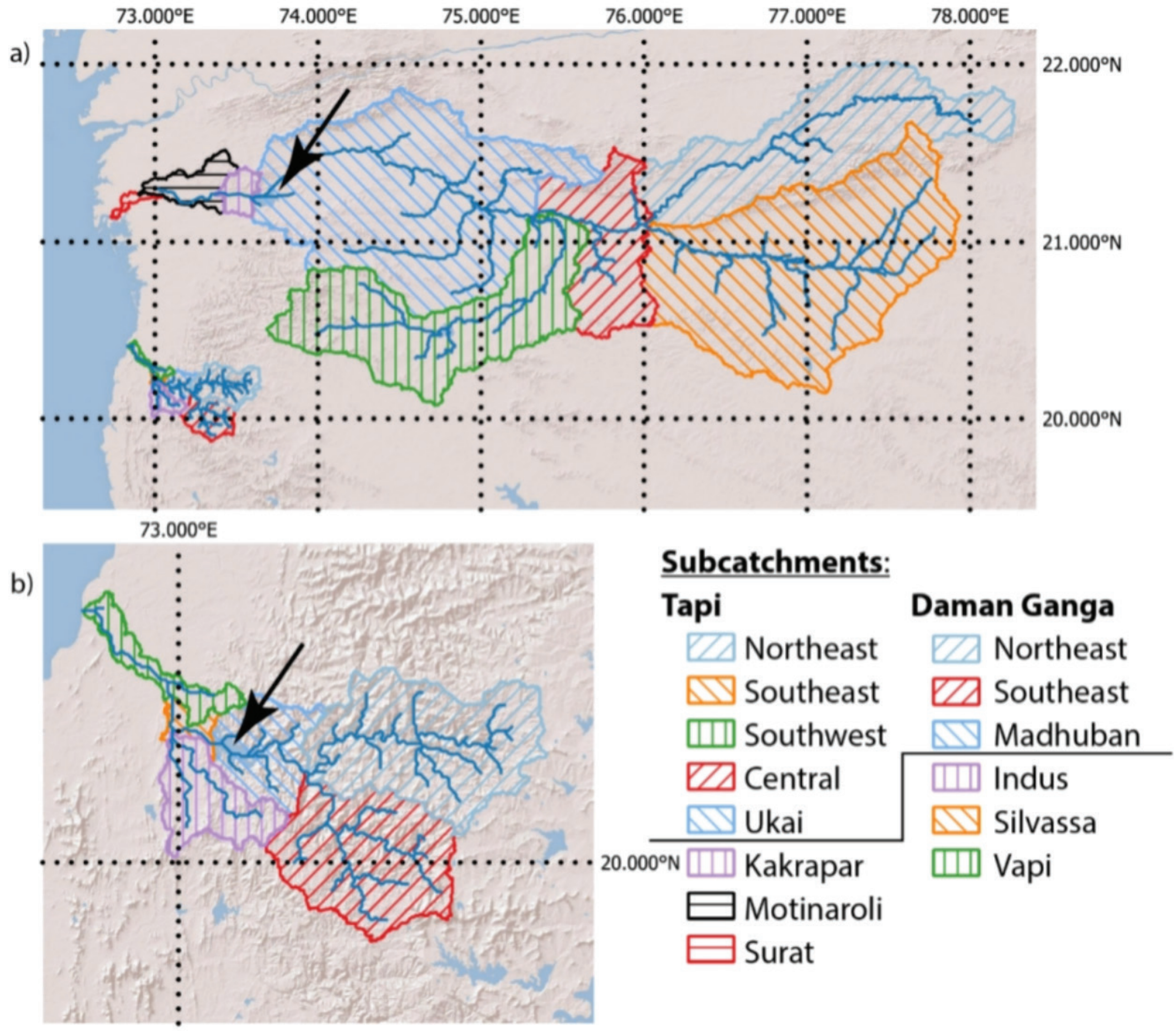


Figure 4.3.1. Catchment maps of Tapi (a) and Daman Ganga (b) showing the extent of the sub-catchments including the Ukai and Madhuban reservoirs. The black arrows point towards the reservoirs and the black line in the legend indicates the position of the reservoir along the downstream gradient. Note that the surface area covering the parts downstream of the reservoirs, i.e., Kakrapar, Motinaroli and Surat for Tapi, and Indus, Silvassa and Vapi for Daman Ganga are relatively small compared to the whole catchment, especially in Tapi.

water regulation and abstraction is limited. Constant abstraction rates were applied to both reservoirs, i.e., Ukai and Madhuban, to reach average annual runoff that were consistent with those reported in Gupta et al. (2022). Nevertheless, discharge data for calibration and validation was available from two stations in Tapi catchment, at Sarangkheda (21.4283˚N, 74.5272˚E; within Ukai sub-catchment in Figure 4.3.1.) and Motinaroli (21.2648˚N, 72.9110˚E; within Motinaroli sub-catchment in Figure 4.3.1.), and one station in Daman Ganga catchment, at Silvassa (20.2681˚N, 72.9856˚E; within Silvassa sub-catchment in Figure 4.3.1.). Both Motinaroli and Silvassa discharge stations are located downstream of the main reservoirs and their data was bias corrected to yield annual runoff consistent with

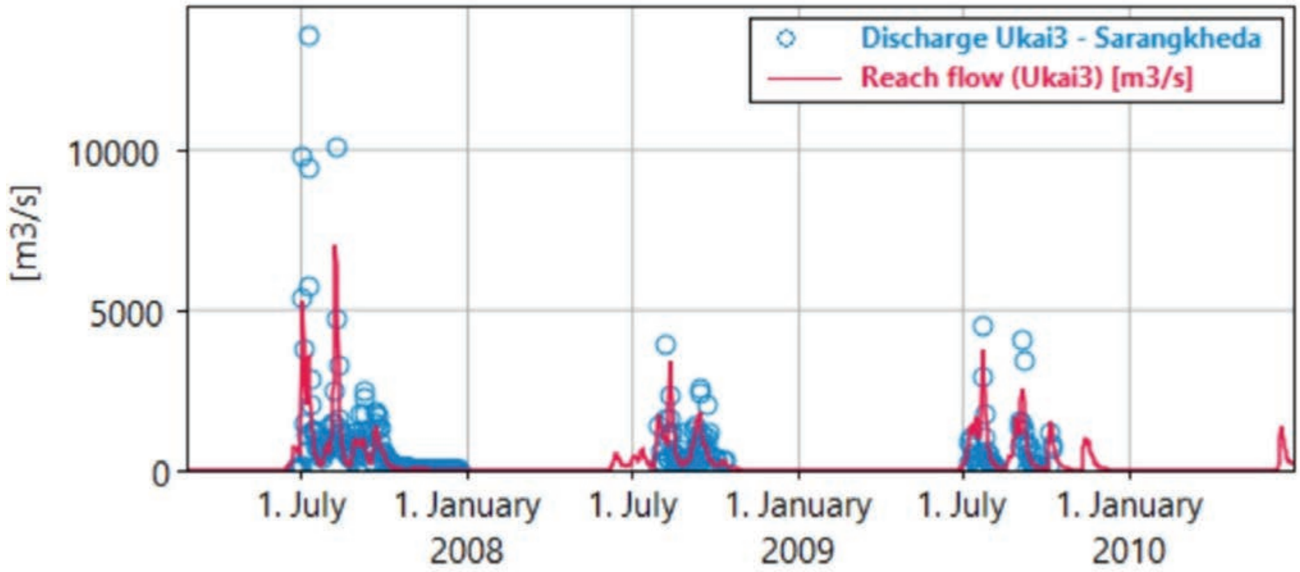


Figure 4.3.2. Comparison between observed (blue dots) and modeled (pink line) river discharge in Tapi river at Sarangkheda station.

those reported by Gupta et al. (2022). Discharge data from Sarangkheda located upstream of Ukai reservoir was consistent with Gupta et al. (2022) without any bias correction. Simulated river flow was associated with good statistics in Tapi River when evaluated against Sarangkheda data (Nash–Sutcliffe efficiency-NSE of 0.61; Kling–Gupta efficiency-KGE of 0.68; Spearman's rank correlation coefficient-SRCC of 0.76; Figure 4.3.2.). When compared to discharge data located downstream of the reservoirs, simulated river flow was associated with less good statistics (NSE < 0 to 0.15; KGE of 0.40–0.42; SRCC of 0.66–0.67), although the seasonal variations and overall amplitude of the high flow events were captured. This decrease in model performance downstream can be attributed to the presence of large dams and a high degree of river flow abstraction (Gupta et al., 2022) as well as our lack of knowledge and data on the management of these water resources.

4.3.2 Macroplastic input data to riverbanks

Daily counts of plastic items deposited on riverbanks are required as input for INCA-Macroplastic. Hence, the proportion of mismanaged plastic waste reaching riverbanks daily needs to be estimated as well as the types of plastics, e.g., plastic bags or bottles.

Here we chose to use two approaches, the exponentially decreasing emission ratios with distance to river modified from Borrelle et al. (2020), and a simplified version of the Meijer et al. (2021) approach. In the former it is straightforward to implement the following equation:

$$\alpha = 1 - \mathrm{U}\log_{\mathrm{d}}(D + 1) \qquad \text{......}\textit{Equation 1}$$

where α is the proportion of plastic waste reaching the riverbanks or emission ratio, D is the distance to the riverbanks, U is a uniformly distributed random variable (0.9 - 1.0) and d is the distance over which a plastic item can no longer reach the riverbanks. As a realistic estimate for d, we used 10 km yielding lower α values than if d would take higher values. As an alternative estimation of α, we considered the probability for mismanaged plastic waste transportation per kilometre following Meijer et al. (2021) with only two main land use types, urban and natural, associated with 0.60 and 0.15 as specific probability. Hence, if a given area is 100% natural, a plastic item has a probability of 15% by kilometre of distance to river to reach the riverbanks.

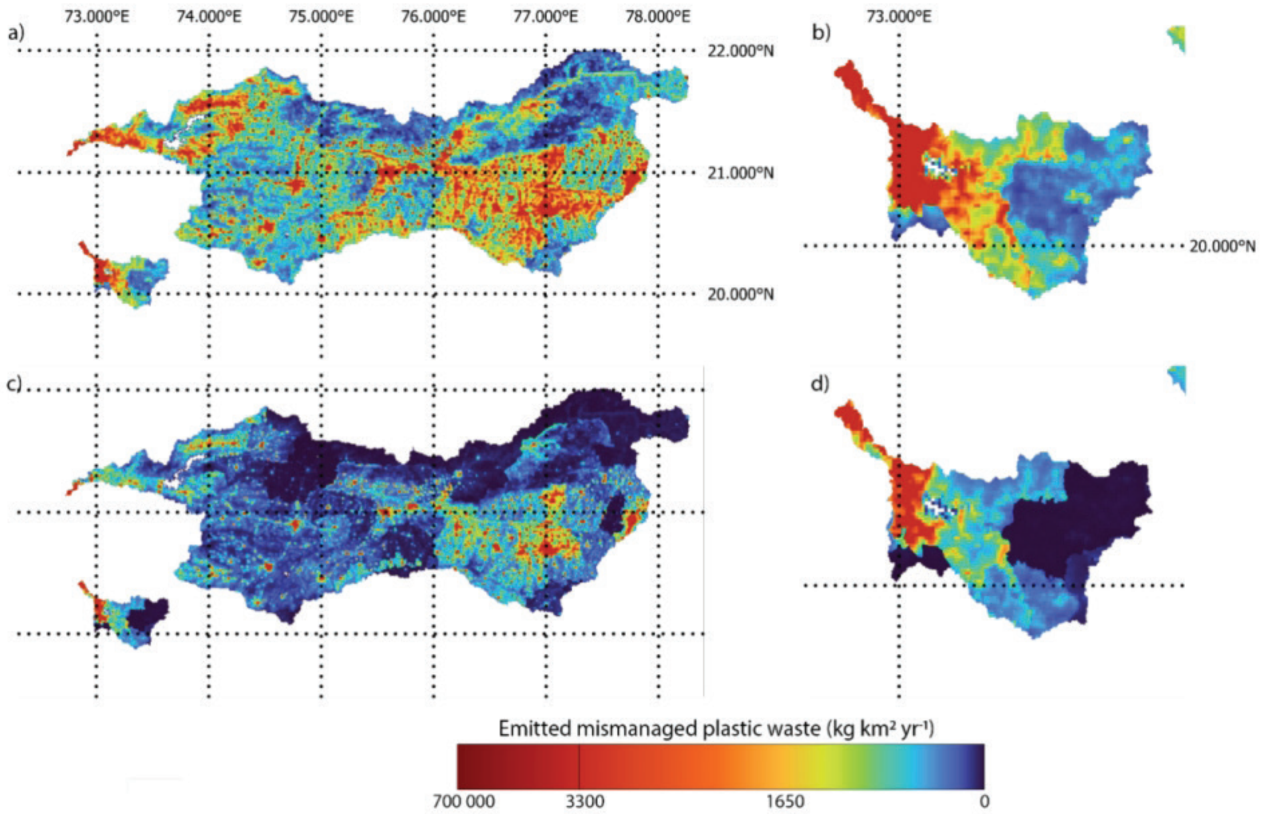


Figure 4.3.3 Catchment maps of Tapi and Daman Ganga (a and c) as well as Daman Ganga close-up (b and d) showing estimated emitted mismanaged plastic waste to riverbanks in 2020 calculated from mismanaged plastic waste, as shown in Figure 4.2.4., and emission ratios determined with Eq. 1. Panels a) and b) display the scaled emitted mismanaged waste while panels c) and d) display the unscaled emitted mismanaged waste. Note that the colorbar scale is not linear above 3300 kg km^2 yr^{-1}.

This alternative α values ranged between 10% and 110% of the values determined with Equation 1. Hence this range of values was taken as upper and lower boundary for α into our uncertainty analysis. Note that in both cases, the emission ratio quickly decreases as we move further away from the river.

Figure 4.3.3 display one estimation of the emitted mismanaged plastic waste in both catchments in 2020. Note that the scale bar is the same as in Figure 4.2.5. Compared with mismanaged plastic waste (Figure 4.2.5.), the influence of the river network is made apparent with higher values closer to the rivers.

Regarding plastic types, we assumed that plastic waste deposited on riverbanks were distributed among bags (30%), bottles (30%), food and other containers (30%) and other items (10%; Matthews et al., 2021).

Considering the exponential increase in plastic waste production (Figure 4.2.4.), the plastic waste inputs to riverbanks were estimated over 1979-2020 with the scaled and unscaled datasets as well as with or without accumulation of mismanaged plastic waste on land over time. When accumulation of plastic waste over time was accounted for, the total stock of plastic waste on land, including newly emitted and 50% of legacy waste from previous year, was assumed to be mobilizable each year. Figure 4.3.4. displays the average plastic waste emissions to riverbanks in Tapi and Daman Ganga following the four possible emission trajectories.

Interestingly, the four emission trajectories follow a different pattern in each catchment. In Tapi catchment, the emission ratio is lower than in Daman Ganga catchment, yielding relatively lower

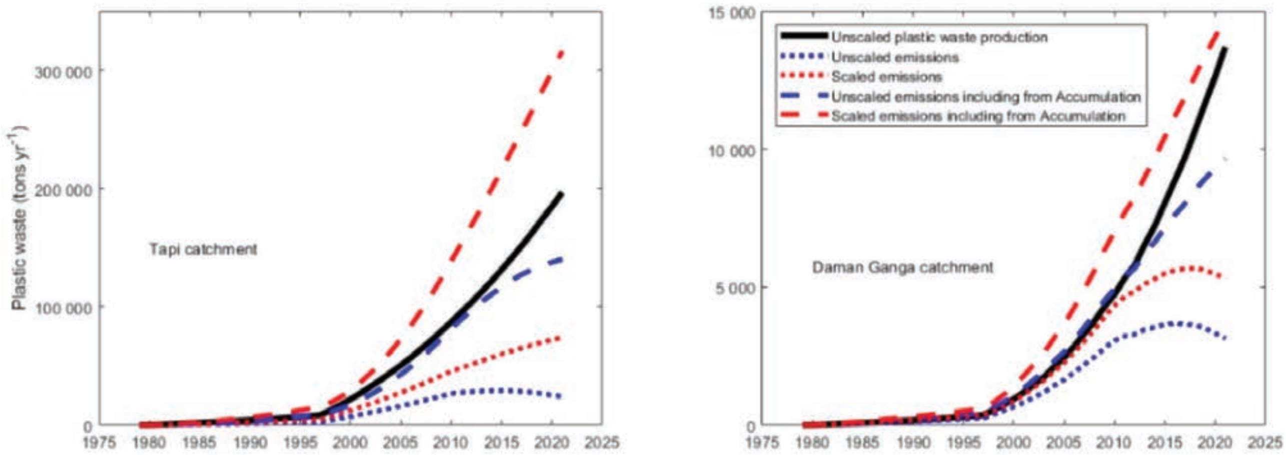


Figure 4.3.4. Comparison of average plastic waste production over 1979-2020 in Tapi (left panel) and Daman Ganga catchments (right panel) and emitted plastic waste to riverbanks following unscaled and scaled mismanaged plastic waste rates with or without long-term accumulation on land.

plastic waste emissions, i.e., a smaller fraction of the plastic waste production is exported each year. However, this also means that a larger fraction of the yearly mismanaged plastic waste production in Tapi catchment remains in the environment and is available for export in the following years compared to Daman Ganga catchment. The lack of knowledge on current status and management of past waste led us to consider a wider range of possible trajectories and, in the end, adds on the uncertainty of the modelled results.

4.3.3 Main results from macroplastic river modeling

The modelled results show that the exports to the sea are quite uncertain, as expected, given the lack of constraint on the plastic emissions (Figure 4.3.5.). The INCA-Macroplastic could not be calibrated because of the lack of observed macroplastic fluxes and counts in various river compartments. Nevertheless, the model was calibrated slightly differently in Tapi and Daman Ganga catchments. For the former, the calibration was made to avoid accumulation of plastics in sediment (Figure 4.3.5. c), but to allow some accumulation of plastics in river vegetation (Figure 4.3.5. e). In Daman Ganga, in contrast, the model was calibrated to avoid accumulation in both sediment and vegetation. In consequence, in Daman Ganga the plastic amounts in sediment and vegetation do not exceed the amounts of plastics exported every year. In Tapi, this is also true for the sediment but not in the vegetation where the plastic amounts rapidly exceeded the annual export to the sea.

The four emission trajectories, i.e., scaled or unscaled, with or without accumulation, have a large influence on the various fluxes and stores dynamics. In fact, only the unscaled trajectories in Daman Ganga including that with long-term accumulation, tend to show a decrease in exports to sea from 2015 Figure 4.3.5. b). In the other cases, the improvement in waste management did not compensate for the increase in plastic waste generation (Figure 4.2.4.). This continuous increase can be attributed to the remobilization of plastic accumulated on land over time but also, in the case of Tapi River, to those accumulated in the river vegetation (Figure 4.3.5. e). This is why, even the trajectories without accumulation do not show a significant decreasing trend in Tapi River. Note that this discrepancy in the results from the two rivers is only the result of our calibration and cannot be verified yet. Nevertheless, it illustrates the impact of accounting for plastic mass flows between the various compartment of the environment over time.

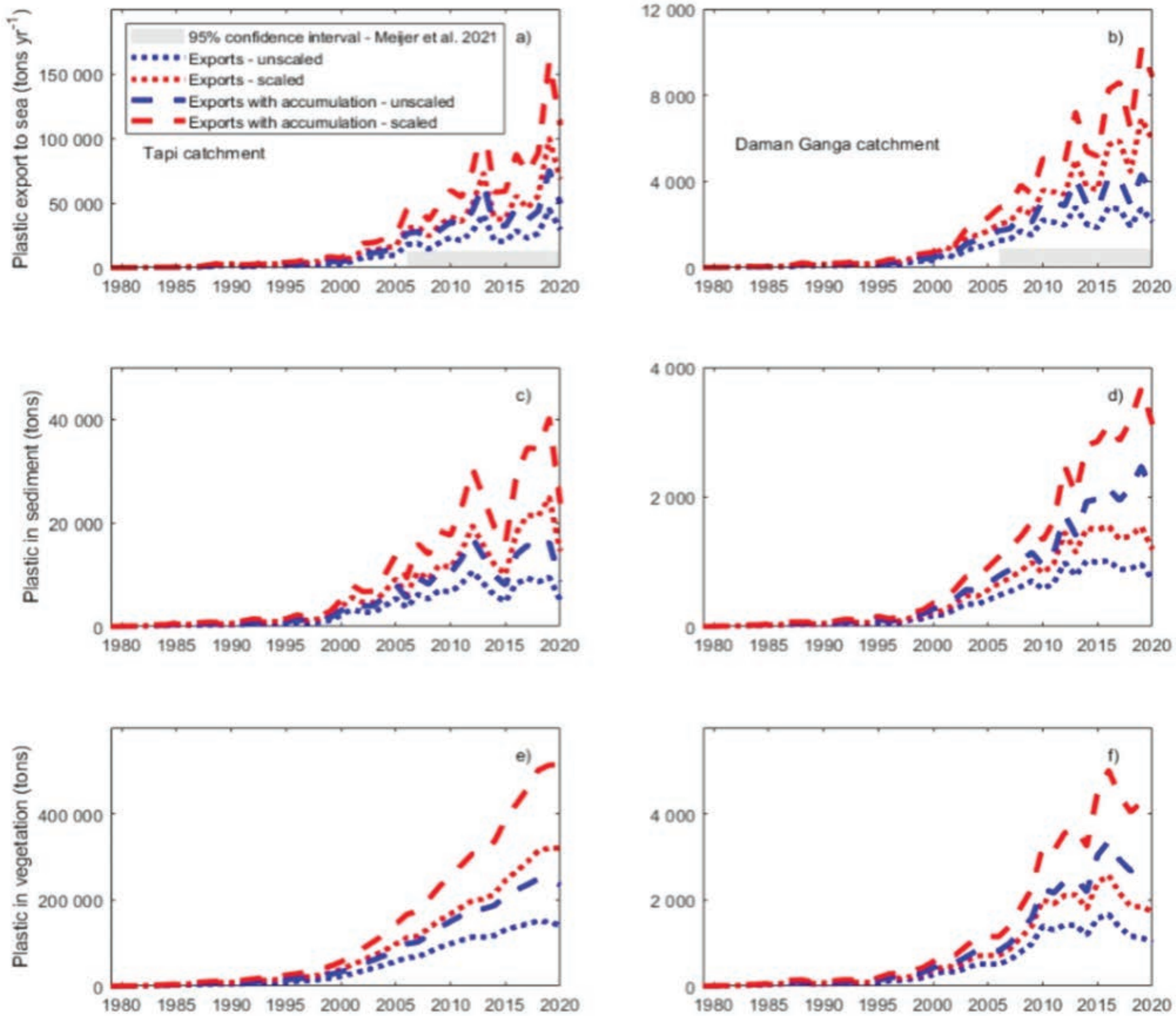


Figure 4.3.5. Modelled plastic exports to sea (a and b), plastic content in river sediment (c and d) and plastic in river vegetation (e and f) in Tapi (a, c and e) and Daman Ganga (b, d and f) rivers for the four plastic waste emission trajectories over 1979-2020. The estimation of plastic exports to sea from Meijer et al. (2021) are also included for comparison. Note that these estimations were obtained with the default set of parameters which can be considered as relatively pessimistic, i.e., yielding among the highest values for plastic exports.

Regarding the four different plastic types, Figure 4.3.6. shows that the except for plastic bags, the relative importance of each type remains unchanged through the three compartments of the river in Tapi and Daman Ganga. Once again, this reflects our calibration where we set up the model to have frequent exchange between the compartments. Apart from small differences reflecting different behaviours of the plastic types within the river current, e.g., different size, area and drag coefficient, plastic bag is the only type showing large difference between the compartments. In fact, it is the only type undergoing tearing when it is trapped in vegetation leading to rapid fragmentation. This is made apparent in Figure 4.3.6. h and j where plastic bags represent a much lower fraction of the total plastics in vegetation than in the inputs or in the

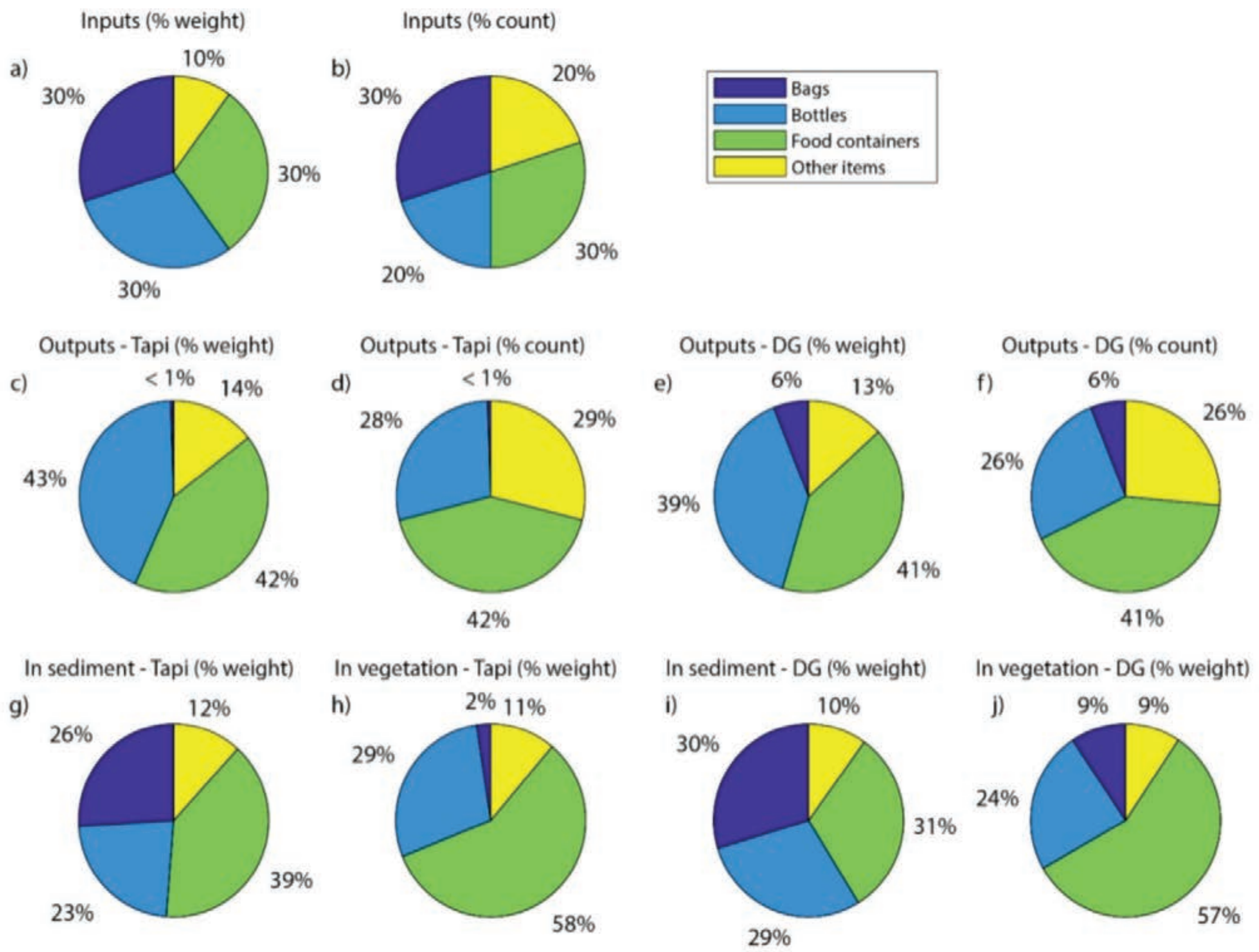


Figure 4.3.6. Distribution of plastic types within inputs to riverbanks (a and b), outputs to sea (c–f), sediment (g–h) and vegetation (i–j) in Tapi and Daman Ganga rivers. Note that the distribution of plastic types in inputs was the same for Tapi and Daman Ganga. For inputs and outputs, the distribution is showed by count and weight while for sediment and vegetation it is only showed by weight.

sediments. As a consequence, most of the plastic bags do not reach the sea (Figure 4.3.6. c–f). The difference in plastic bag outputs between Tapi and Daman Ganga is likely related to the fact that plastic bags have a much larger residence time in Tapi River, allowing them to be fragmented.

Over a typical year, fluxes to the sea are several orders of magnitude higher during the wet season (June–October) than over the rest of the year (Figure 4.3.7.). Model results indicate that, most of the exports to the sea are concentrated within three months, July to September, representing 82% and 91% of the annual flux in Tapi and Daman Ganga rivers, respectively. This proportion later reaches 97% and 99% for the two rivers, respectively, if we consider the period from June to October.

4.3.4 Extrapolating from macroplastics to microplastics

Estimations of microplastic discharge within a catchment requires to consider a large set of emission pathways and is generally associated with large uncertainty (e.g., Boucher et al., 2019; Clayer et al., 2021). In addition to fragmentation of macroplastics littered in the environment, microplastic can be emitted to rivers *inter alia* through direct discharge of wastewater, road (e.g., fragmentation of tyre wear) and agricultural runoff,

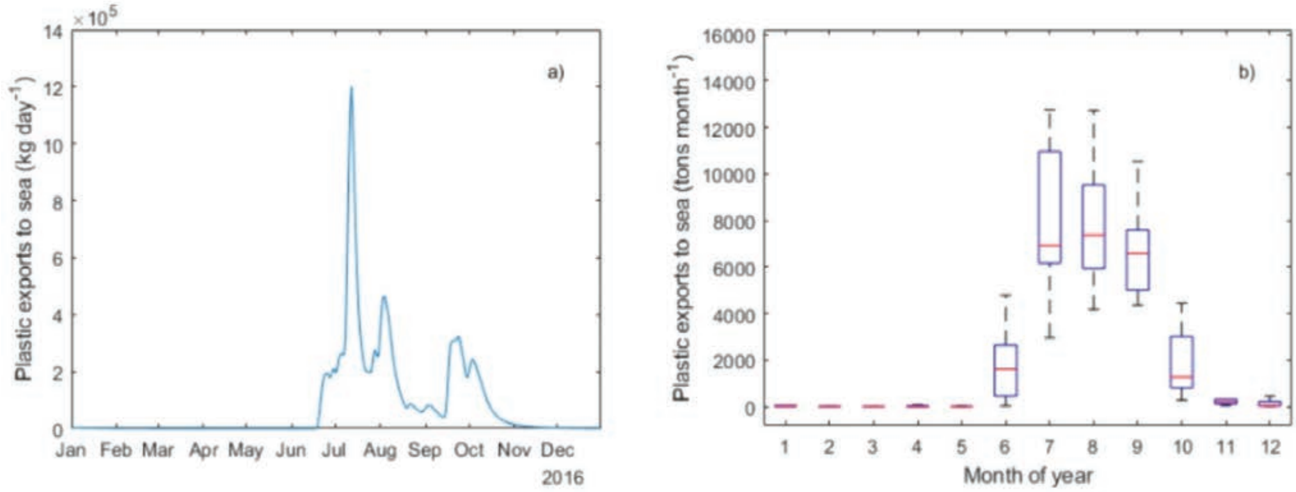


Figure 4.3.7. Daily (a) and monthly (b) plastic exports to sea from Tapi River estimated with the default values. Monthly exports were calculated over 2010-2020.

as well as emissions from construction, recreation sites, plastic production and recycling industries (Clayer et al., 2021). Considering all these emission pathways in Tapi and Daman Ganga catchments would introduce further large uncertainties in the estimation of microplastic discharge to the rivers and ultimately to the sea because of the lack of data.

Based on the macroplastic model results, it can simply be estimated that 80% and 95% of the plastic bags emitted to Daman Ganga and Tapi rivers, respectively, undergo fragmentation before reaching the sea (Figure 4.3.6.). In addition, we can assume that between 0.05% and 0.5% (Clayer et al., 2021) of the mismanaged macroplastics (except plastic bags) ends up as emitted microplastics to the river. Besides, it is likely that the majority of the microplastic river load will get exported through the sea over time, since the majority of microplastics trapped in sediment will eventually get remobilized during flooding events (Hurley et al., 2018). Here, for simplicity and as a maximum estimate, we consider that all microplastics reaching the river, are exported to the sea.

Figure 4.3.8. below shows the estimated microplastic export to sea over time following the two extreme plastic emission trajectories as the lower and upper

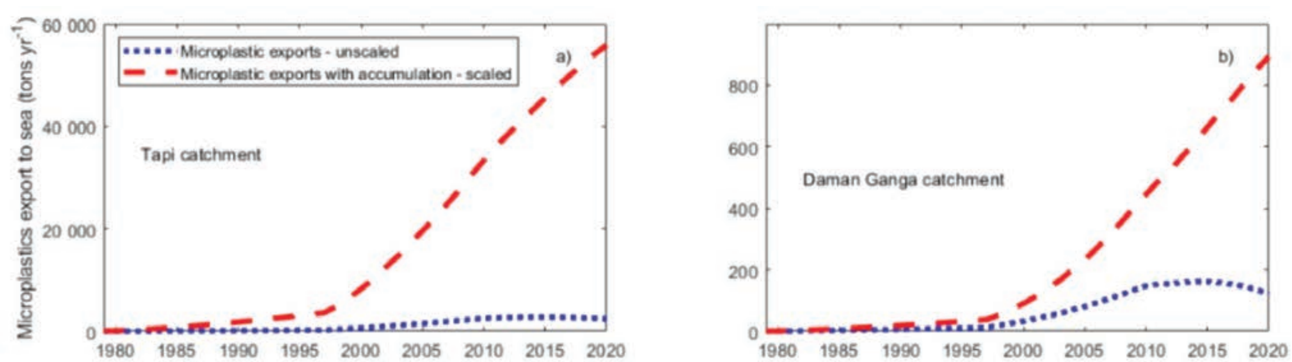


Figure 4.3.8. Microplastics export to sea from Tapi (a) and Daman Ganga (b) rivers over 1979-2020, extrapolated from the microplastic model results, as described in the text.

boundaries. From Tapi River, it is thus estimated that between 2000 and 58000 tons of microplastic were exported to the sea in 2020. For Daman Ganga, this quantity ranges between 120 and 950 tons in 2020. However, as noted above, these estimates are highly uncertain. Uncertainty would likely be reduced using a model specifically designed for microplastics (e.g., Whitehead et al., 2021), as well as microplastic concentrations in various media, e.g., water, sediment, soils, from various sites across the catchment and under a wide range of hydrological conditions.

4.4 Future perspectives and recommendations

The macroplastic model should be validated against measured macroplastic fluxes over a wide range of hydrological conditions, obtained in various seasons and at various sites across the catchments. As seen in Figure 4.3.7., most of the annual plastic export to the sea is expected to be concentrated over a few months during the wet season particularly during high flow events. In addition to floating macroplastics, the dynamic in other river compartments should be investigated. The comparison of two contrasted model calibrations showed that accumulation of plastics in vegetation will likely lead to higher future plastic exports to sea. An equivalent approach to the “Beach litter deep dive” approach (Falk-Andersson, 2021) could be taken to provide knowledge on river plastics origin and age. This information would help to better understand how plastics are transported and trapped over time in the river systems.

Similarly, the long-term fate of mismanaged plastics accumulated on land over the last decade needs to be better constrained. Information on total amounts of past accumulated plastic in landfills is required to better appreciate the magnitude of mismanaged plastic stores on land. In addition, information on management and remediation of these landfills in the past and future can further improve the model to estimate the likelihood of these debris to be emitted to aquatic ecosystems. It would also be beneficial to quantify the abundance of illegal dumping and burning sites and the amount of waste processed in them, in the past decades and at present. It is therefore of primary importance to continue reporting quantities of collected and processed waste across Indian municipalities, as well as its plastic content, to provide more precise estimations of mismanaged plastic waste. The role of informal waste pickers is also currently neglected although they likely play a significant role in reducing plastic mismanagement. Quantitative data on plastic waste collected by the informal sector and on its end-of-life fate is required to take this important waste processing route of the waste management chain in India.

In the presented model, mismanaged plastic waste was assumed to be spatially distributed according to population density, i.e., higher levels of waste in denser populated areas. While this might be realistic for recent littering, ultimately waste is transferred to long-term landfill sites. Hence, assuming that mismanaged waste, when not transported, remains in densely populated areas are less realistic. Information on the location, size, and amount of waste present in these infrastructures would be beneficial for modelling outputs.

In the present study, the impact of the water reservoir management and water diversion in irrigation canals was ignored because of the lack of information. Better knowledge on plastic litter behaviours in reservoir would be further beneficial for realistic modelling outputs.

Chapter 5

SOCIO-ECONOMIC DIMENSIONS OF PLASTIC WASTE IN GUJARAT AND INDIA

5.1 Recent Policy Developments India/ Gujarat State

The Plastic Waste Management (Amendment) Rules, 2022 contributes to strengthening the circular economy of plastic packaging waste and promoting the development of new plastic alternatives. The rules mandate Extended Producer Responsibility (EPR) thus incentivizing companies to enter the recycling market and develop and implement circular economy solutions for plastic products. Against the backdrop of a progressive policy framework, the private sector is expected to play a crucial role in driving solutions to the plastics challenge, leading material, technology, and financing innovations.

5.1.1 Evolution of PWM policies in India

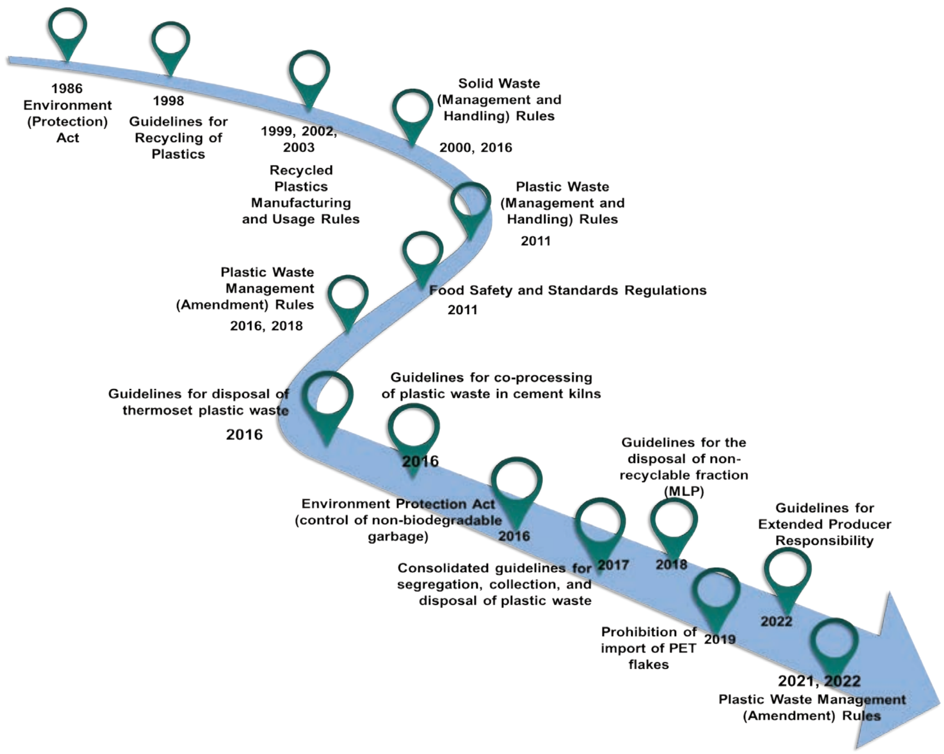


Figure 5.1.1. Evolution of PWM policies in India (Source: (adapted from Annexure 2) (Kapur Bakshi et al., 2021))

5.1.2 PWM Rules (Amendment) 2021, 2022

The Plastic Waste Management (Amendment) Rules, 2022 provide "a framework to strengthen the circular economy of plastic packaging waste and promote alternatives to plastic" (GOI, 2022). In addition to improving the circular economy of plastic packaging waste, the rules encourage the development of new plastic alternatives (PTI, 2022). The Plastic Waste Management (Amendment) Rules, 2021 prohibit the use of single use plastic (SUP) items by 2022 while the thickness of plastic bags has been increased from 50 microns to 75 microns and 120 microns with effect from the 30th September 2021 and 31st December respectively (GOI, 2021). The key goal of the 2022 amendment is to operationalize extended producer responsibility (EPR) within the ambit of the Plastic Waste Management Rules, 2016. The amended rules address a vast number of unresolved issues surrounding post-consumer plastic waste and help streamline stakeholder obligations under India's EPR regime (Shah, 2022)

The amendment, in a significant first, allows for the sale and purchase of surplus EPR certificates, establishing a market mechanism for plastic waste management. The guidelines also call for establishing a centralised online portal by the Central Pollution Control Board (CPCB) for the registration as well as "filing of annual returns by producers, importers and brand-owners, plastic waste processors of plastic packaging waste by 31st March, 2022". Environmental compensation has also been introduced which will be levied based upon 'polluter pays principle', with respect to non-fulfilment of EPR targets by producers, importers, and brand owners (GOI, 2022).

5.1.3 Role of Extended Producer Responsibility in closing the loop

EPR is based on the concept of 'management of the whole-lifecycle of products' combined with a circular economy framework and the polluter-pays-principle. It focuses on making producers responsible for reduction of the environmental impact of their products (Pani & Pathak, 2021) Thereby, EPR encourages producers to conserve raw materials, reconsider product design, technology, production processes, and be responsible for environmentally safe consumption and disposal of their products (Fadeeva & Van Berkel, 2021). A robust regulatory architecture, operational dynamics and ecosystem catalysts are crucial for steering an effective EPR system (Pani & Pathak, 2021). The PWM (Amendment) Rules 2022 mandates recycling and reusing a certain percentage of plastic produced by manufacturers,

Table 5.1.1 Categorization of SUPs, as per amendment 2022 (GOI, 2022)

Category	Description
Category 1	Rigid plastic packaging
Category 2	Flexible plastic packaging of single layer or multilayer (more than one layer with different types of plastic), plastic sheets or like and covers made of plastic sheet, carry bags, plastic sachet or pouches
Category 3	Multi layered plastic packaging (at least one layer of plastic and at least one layer of material other than plastic)
Category 4	Plastic sheet or like used for packaging as well as carry bags made of compostable plastics

importers, and brand owners. This is to incentivize more companies to enter the recycling market and create a circular economy for plastic products.

5.1.4 Status and capacity of Plastic Waste Management in Gujarat (Single Use Plastics)

The state of Gujarat reports the highest volume of hazardous waste generated in the country. During 2019-2020, a total of 24.85 lakh metric tons (LMT or Hundred thousand metric tons) (i.e., around 28% of the total hazardous waste generated in India) was from Gujarat (CPCB, 2021). A total of 1049 units (1027 plastic manufacturing/ recycling units, 12 compostable plastic units and 10 multi-layered plastic units) are registered in the State (CPCB, 2021). In February 2018, all urban local bodies (ULBs) were instructed by Secretary, Urban Development Department, to ban the use of plastic material of less than 50 microns. In the Plastic Waste Management by-laws, the "no plastic carry bags/films <50 microns' thickness is stocked, sold and used in cities/towns" term has been covered. The most recent PWM Rules notification mandate thickness of plastic carry bags to be increased from 50 to 75 microns from 30th September 2021 and to 120 microns with effect from the 31st December, 2022 (GOI, 2022).

As per Ministry of Environment, Forest and Climate Change, the Urban Development and Urban Housing Department, (Government of Gujarat) has constituted Special Task Force (STF) and also prepared a comprehensive action plan focusing on eliminating certain Single-Use Plastic Products (SUPPs), implementing the provisions set by the PWM Rules, and creating awareness on the issue of elimination of SUPPs (GPCB, 2021). As mandated by the public health by-laws for the implementation of the Solid Waste Management Rules 2016, "no burning of waste" and "no dumping of waste on drains and riverbank" has been implemented and enforced by all ULBs in the state. Gujarat has identified three model cities, Surat, Vadodara and Rajkot, all of which have achieved 100% door to door collection, waste segregation at household level and 100% of wet, dry, sanitary, hazardous and domestic hazardous waste processing. Surat has a 1200 tonnes per day (TPD) plant working for solid waste management processing, construction and demolition waste processing capacity of 300 TPD, plastic waste processing and recycling plant of 70 TPD and a 200 MT material recovery facility (MRF). Vadodara has a plastic waste processing and recycling plant of 200 TPD and 50 MT MRF facility. Whereas, Rajkot has a plastic waste processing and recycling plant of 50 TPD and a 50 MT MRF facility (GPCB, 2021)

5.1.5 Drivers and deterrents to circular economy of plastic products, in India and Gujarat

Public awareness can create an enabling environment for policy implementation. Community-led initiatives commonly involve promoting and incentivizing recycling, using waste plastics for energy recovery and re-purposing waste plastics for building materials. In most cases these initiatives are still at pilot scale and limited to one geographical location only, and their scalability has the potential to drive circular economy of plastic products. Energy recovery processes, although it may solve part of the plastic waste issue, are not the most preferable option for strengthening the circular economy of the resource due to down cycling of the plastic resource out of circulation. Also, across all initiatives undertaken in India, the focus is on facilitating collection and recycling, and there are only a few examples of employing reuse and re-purposing strategies. In general, initiatives tend to focus on the beginning or end of the plastic life cycle (Tyagi et al., 2021). Segregation of waste at source and segregated collection is inefficient, especially in rural areas. Occupational & health safety hazards linked with waste collection and segregation (for women and children in particular) act as deterrents (TPT Bureau, 2021). Other deterrents to a circular economy for plastic products include lack of market-based instruments for recycled products, few regulatory measures for effective functioning of business models, and limited cooperation between different stakeholders across the PW value chain (Ledsham, 2018). In addition, the market price of fossil fuels for virgin plastic production continues to be lower than for recycled plastics, making it more viable for producers to use virgin plastic over recycled plastics. Stimulating the market demand for recycled plastics would be a potential way of making domestic recycling streams viable and increasingly circular. Regulatory steps to increase the competitiveness and use of recycled plastic in new products is already under way, as evidenced by the latest guidelines on Extended Producer Responsibility for plastic packaging under the PWM Rules 2022, mandating minimum levels of recycled plastic content in packaging for all entities, including producers, brand owners and importers in a step-wise and categorized approach (GOI 2022). Gujarat now has a streamlined co-processing model for the plastic waste generated from the paper and other industries; with the Gujarat Pollution Control Board (GPCB) having subsidised adoption of co-processing facilities, regular review and training sessions among others (Shah, 2022). Co-processing waste to energy and cement are potentially viable alternatives for waste which cannot be reused, re-purposed or recycled (CPCB, 2017). However, from a circular economy point of view it is not the optimal solution as the resource value is not kept in the loop. When opting for these types of waste management options, environmental impacts of release of ‘substances of concern’, health implications due to release of carcinogenic substances and economic considerations are key concerns (Hahladakis et al., 2020).

5.1.6 Role of key players in policy implementation

The PWM rules in India have strategically evolved over the years to include key aspects based on recommendations from key stakeholders and drawing on PWM experiences from regional and international levels. The lack of a strong implementation network is currently a barrier to effective PWM. In India, the transition to a circular plastics economy will necessitate extensive (financial and regulatory) collaboration among key stakeholders, including regulators, policymakers, corporations, financial institutions, and civil society actors. In addition to this, technological advancement and financial solutions are drivers of effective waste management (Kapur Bakshi et al., 2021).

Government stakeholders at national and state levels must be accountable for developing an overarching policy framework including regulations, market-based instruments, etc. They must also be responsible for facilitation of capacity building activities for better and efficient management of plastic waste. Public institutions have the responsibility of monitoring management practices, ensuring compliance and supporting policy inception, as well as review the information annually reported by states. At the city/local level, ULBs play the crucial role of developing and implementing municipal level policy frameworks and bye-laws and engaging with private players to support waste management activities (NITI Aayog, UNDP, 2021). Strategic investments in local collection, segregation and recycling infrastructure by corporates and financial institutions can result in diverting plastic waste away from landfills, open burning, and marine environment. The private sector must play a crucial role in driving solutions to the plastics challenge-leading material, technology, and financing innovations. All these initiatives will not see fruition in the absence of strong civil society, community and and NGO participation - all of these play an important role towards implementation of policy on the ground. As the community and community-based organisations are more aware of their local conditions, their participation is key towards identifying waste management issues, managing household waste, improving engagement and willingness to pay for services and solutions. Community contribution and volunteerism can be seen as the social capital that is a driver for the success of waste management interventions.

5.1.7 Overview of collaborations, alliances, and initiatives for policy implementation

The combined roles of public sector, industry and community is key for ensuring that policy is accepted by everyone leading towards effective implementation of policy. Civil society in particular has a key role to ensure a just transition of plastic waste management in the sector (especially for the under-represented informal sector) by proposing changes as well as aligning efforts to existing policy frameworks. The dovetailing of efforts by all stakeholders through various collaborations, alliances and initiatives provides a structured actionable roadmap for policy implementation.

5.1.7.1 Public Sector led initiatives

As a part of India's commitment to effective waste & pollution management, several initiatives have been undertaken. The Public Sector has provided a conducive policy framework and is promoting responsible behaviour, with a focus on technological advancement. As a part of India's commitment, multiple large-scale national initiatives such as 'Swachh Bharat Mission', 'Waste to Wealth Mission', amongst others have been undertaken in collaboration with industry and community stakeholders. Initiatives such as 'Plastic India Hackathon 2021' by the MoEFCC for innovating alternative solutions to Single-use plastic and 'Clean and Green' campaign 2022, by MoHUA are aimed at raising awareness and a sense of responsibility amongst citizens for active participation in single-use plastic ban and enforcement.

5.1.7.2 Industry led initiatives

The industry plays a significant role for a circular economy in the waste management sector. Some of their efforts are mentioned briefly below.

Khadi and Village Industries Commission's (KVIC) REducing PLAstic in Nature (REPLAN) project, launched in 2018, with an aim to remove existing waste plastic material from nature for use in a semi-permanent manner as a part of its commitment to *Swachh Bharat Abhiyaan*. KVIC production of waste-plastic mixed handmade paper through their patented Plastic-mixed Handmade Paper is likely to serve the twin objectives of protecting the environment alongside creating sustainable employment (PIB Delhi, 2021).

Un-Plastic Collective (UPC) is another initiative launched by the United Nations Environment Program (UNEP)-India, Confederation of Indian Industry (CII) and WWF-India. The Collective "seeks to minimise externalities of plastics on the ecological and social health of our planet". As a part of the initiative, companies set time-bound, public targets to eliminate unnecessary use of plastic; reuse and circulate plastics through the circular economy; replace plastic with sustainable alternatives or recycled plastics; and translate commitments into meaningful and measurable action. (UPC, n.d.)

Additionally, the United Nations Development Programme (UNDP) India, has partnered with Hindustan Coca-Cola Beverages Private Limited (HCCBPL), Hindustan Unilever Limited (HUL), HDFC Bank & Coca Cola India Foundation (CCIF) and is promoting the collection, segregation and recycling of plastics to support the move towards a circular economy. The project is currently operating in 36 cities, and has established 22 Material Recovery Centres (*Swachhta Kendras*) for sustainable waste management practices. (UNDP India, n.d.)

Recykal, a technology driven solution provider for the waste management ecosystem has partnered with more than 100 ULBs and 125 partner brands in their efforts to connect waste generators, waste aggregators, and waste recyclers to solve challenges (Recykal, n.d.)

5.1.7.3 Community led initiatives

Some of the community led initiatives that have the potential to be replicated and up scaled for better management of plastic waste across India include:

Aviral – Reducing Plastic Waste in the Ganga was launched by The Alliance to End Plastic Waste (The Alliance) and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), in July 2020. As a part of this alliance, Saahas NGO and Waste Warriors Society are supporting the Municipal Corporations of the project sites of Haridwar and Rishikesh to conceptualise sustainable and replicable plastic waste management solutions. Following the two-year pilot in these cities, the partnership aims to scale this initiative across partnering cities in India (Alliance to End Plastic Waste, 2020)

HDFC Bank and Centre for Environment Education (CEE), in collaboration with local municipalities across India have set up 'Plastic *Lao* - *Thaila*/Mask *Pao*' stall- Collection, Drop Point for Non-Biodegradable Recycling Plastic Waste where citizens can drop off their plastic waste in exchange for masks and/or cloth bags (*Thaila*). Centre for Environment Education has partnered with local NGOs from different cities for numerous awareness and implementation campaigns; 'Karwaan Mission' an NGO from Delhi, 'CORE' an NGO from Bhubaneswar, among others.

The India Plastics Pact is a collaboration between World Wildlife Fund (WWF) India and Confederation of Indian Industry (CII) —anchored at the CII-ITC Centre of Excellence for Sustainable Development (CII-ITC CESD), and supported by Waste & Resources Action Programme (WRAP), a global NGO based in the United Kingdom. The India Plastics Pact aims to unite businesses, the government, NGOs, non-profits and other stakeholders to address the barriers to circularity in the plastic packaging sector. Four major targets of this pact are: To eliminate unnecessary and problematic plastic packaging through redesign and innovation; make/design plastic packaging completely reusable, recyclable or compostable; effectively recycle (or compost) plastic packaging; incorporate recycled content across all plastic packaging. (IPP, n.d.)

Grassroots organisations and social enterprises across India have been working with waste pickers,

Figure 5.1.2 Interlinkages between roles of key stakeholders in the PW policy implementation; Source: Adapted from Tyagi et al., 2021

to integrate them into the waste economy. Among these are 'Kabadiwalla Connect' (Chennai), 'Hasiru Dala' (Bengaluru), and 'Chintan' (Delhi) that have formulated replicable waste management solutions (Khare, 2022)

5.2 Perspectives based on stakeholder interviews

The industrial sector is a key stakeholder in the waste management system. Given the systemic nature of the waste management challenge, in order to address it, it is key to involve industry perspectives in the plastic life cycle – at various levels – regulatory, technological and from a business standpoint. What does this mean in practice? In the plastics value chain, this would involve engaging the industry actors at the points where products or packaging are manufactured, where brands use the packaging in their products, waste management companies and recyclers. In the Indian plastics value chain, the division across the organized (formal) and unorganized (small, informal) categories roughly mirrors that of the Indian private sector. This means that many small, medium and micro enterprises (MSME's) use plastic and generates plastic waste, and that recycling operations follow a similar pattern.[1] Large Indian brands, mostly in the FMCG (Fast-moving consumer goods) sector are members of one or more voluntary initiatives organized by different associations (as outlined in earlier chapter); some of these are polymer-specific - with PET being the polymer most discussed, most collected and most recycled. Others tackle only waste management, are active in specific locations, or only focus on policy. Many prominent NGOs partner with the large brands (e.g Tata, Reliance) but these efforts have thus far, been on a small scale, fragmented, and therefore, not as impactful as may be desired. For companies manufacturing plastic products and using plastic packaging, especially SUPs, the recent EPR guidelines (2022) have necessitated new thinking and action. These guidelines also have the potential to scale up impact because they are applicable throughout the country and apply to relevant industry stakeholders across the value chain.

As part of the INOPOL project, key stakeholders from the industry sector were interviewed with respect to their views on the informal sector, policy and business environment (spec. regarding impact of Plastic Waste Management Rules (PWMR) and EPR) as well as alternative materials options to plastic (e.g., biodegradables).

The informal sector figures prominently in the consideration of supply chain management as well as economic and social concerns. All the industry stakeholders interviewed were aware of the challenges and opportunities that the informal sector offers. In terms of new initiatives to integrate the informal sector, a model that has gained ground is to collaborate with municipalities (who provide space and formal sanction to companies and the informal sector to collaborate on agreed terms), NGOs and/or informal sector workers directly. This model has been trialed in various cities across India. One stakeholder went so far as to describe this collaboration a '*Win-win situation for the company, informal sector and municipality*'. The informal sector representatives that collaborate are provided with certain social security provisions (e.g., health care, digital bank account through the Pradhan Mantri Jan-Dhan Yojana, Aadhar card), the recycling companies secure their supply of required plastic materials and the municipalities reduce their costs for municipal waste collection and support social inclusion. In terms of consideration of social welfare and ethics, one recycling company representative dealing with international customers explained that it is not purely domestic socio-economic concerns that drive such so called 'win-win' outcomes, but rather the international business environment via multinational companies (MNCs). The MNC require strict compliance with respect to ethical sourcing of materials that go into their products (also driven by 'green' and 'ethical' consumer preferences in the global North). When supplier agreements are signed with domestic vendors/recyclers in India, they are required to ensure source traceability and that no child labour or exploitative labour practices are involved – while simultaneously providing remunerative prices. The company representative stated that they work with their Corporate Social Responsibility (CSR) teams as well as NGOs to ensure that these social considerations are taking into account but acknowledge that 'perfect tracking' may not always be possible. Some of the issues that may challenge collaborative private sector-informal sector collector collaborations are questions of trust, quality of material, and other transaction costs. For example, there are persistent issues such as with industrial consumer waste which is expensive, and some problems with post-consumer waste such as colour and washing as well as smell. This requires further research and technological improvements to address.

Discussions with brands and recyclers, as part of the INOPOL project, suggest that industry stakeholders agree in principle with the need for

1 The pattern varies with polymer – the polyolefins, polypropylene and polyethylene, are mostly recycled by small operators while PET is recycled by large companies owing to the cost of equipment needed.

stringent targets and deadlines (as set by the GOI PWMR 2021). One recycling company representative even calling them “brilliant rules”. However, there are also apprehensions. Specifically, with respect to the lack of adequate recycling infrastructure that is needed to comply with EPR rules. Despite this reservation, some industry representatives are of the opinion that this new policy regime can drive investment into the recycling infrastructure in India in the near future. For MSMEs manufacturing plastic packaging, in particular, shifting to a circular economy would entail making ‘better’, that is, more recyclable plastic packaging, which involves large capital expenses, which can be a risky endeavour. Most company representative were aware of the consultative process to draft the PWMR Rules and EPR, however they did not always actively participate and did see the process of policy making as driven by many concerns, that are not necessarily driven by their input. One producer mentioned that they did oppose certain provisions of the SUP bans (e.g., ban on certain SUPs such as straws), but these were not taken into account in the drafting of the rules. The same representative added that the ‘*Burden of EPR implementation should fall on local bodies, not brands. Governments/ULBs have greater clout with respect to changing consumer behaviour.*’ This essentially echoes the view that it is the state that should bear the burden of implementation and not outsource the responsibility of this essential public service to the private/industry sector.

Another business concern for recyclers more generally is the issue of international market prices for oil. The prices of recycled plastic material should ideally be 2-7 percentage lower than virgin plastics, which again depends on the international oil price. One of the recycling companies interviewed is of the opinion that domestic market growth for recycled plastic is so strong that they intend to sell 80 % of their products domestically, instead of the 80 % at present that currently goes into the international market. Such a major scenario shift is not only supported by the policy regime, but also by economic growth prospects.

The Indian industry faces a special challenge with respect to flexible, multi-layer packaging formats. This is on account of the nature of products sold in them and the markets they are sold in. The price sensitivity associated with those products in large sections of society makes it hard for industry to come up with short term solutions or alternatives that allow a low price without compromising the functionality of the packaging. This is for example the case with milk sachets or packaging of other perishable goods such as butter. These packing items are also the most common SUPs that escape into the environment. Their collection by the informal waste-picking system would involve an effort disproportionate to their value in end-of-life markets i.e., material that holds little value for further processing and is possibly incinerated or not used for further processing.

On the issue of biodegradable plastics, there was an overwhelming sense of scepticism. Biodegradable alternatives are more expensive, as well as pollute the waste stream as they are hard to distinguish from plastic waste and are not always degradable under the existing environmental conditions. As one industry representative remarked *‘There is a compulsion by the company to go for these alternatives’.* A critical voice of a major conglomerate also remarked that many of these problems from industry’s perspective can be addressed by an effective implementation of the Solid Waste Management Rules, the Plastic Waste Management Rules and the Extended Producer Responsibility guidelines. In tune with other representatives, consumer awareness was considered an important element to solve some of the waste management issues (including when considering alternatives) in the country, as one company representative stated: *‘Consumers don’t actively look for sustainable products so consumer awareness is very important, as are company policies and capability which can, together, drive move towards more sustainable products/packaging.’*

Some of the concrete suggestions from an industry representative with respect to the EPR were to include (a) social aspects into EPR regulation notification (b) that state-level discrepancies were taken care of and understanding of variations between states better addressed since manufacturing takes place all over India (c) measures to improve traceability and transparency were put into place.

5.3 Role of the informal sector in preventing plastic pollution in regions

This chapter presents an overview of the informal recycling sector in India, including an assessment of its key role in plastic waste management, an analysis of existing informal network structures, and challenges and opportunities with regard to utilizing these to bridge capacity and knowledge gaps toward increasingly sustainable plastic waste management. It must be recognized that there are large geographical and socio-political diversities when addressing the role and network structures of the informal recycling sector, both within and across cities, states, and regions. The narrative presented here is based on interviews with key stakeholders, field visits, expert workshops, online conferences, and secondary literature, and may not be applicable throughout India.

The informal recycling sector (IRS) plays a key role in plastic waste management in India. Data and knowledge on the informal sector scale and recycling capacity is scarce, IRS in India is estimated to consist of 2-4 million people recycling 20-60% of the total recyclable waste (Chikaramane 2014; Chandran et al. 2018). As in most other countries with large informal waste economies, workers in the sector are often representing the urban poor, marginalised socio-economic groups, minorities and migrant workers, with few alternative livelihood opportunities in the formal sector (Gill 2010; Chu and Michael 2019).

The pivotal role of informal structures in providing essential waste management services across Indian cities has been emphasized in numerous studies and country-specific reports (see for example TERI 2018; ESCAP 2019; UNEP et al. 2019). It is becoming increasingly established that the informal sector saves municipalities' significant waste handling costs by collecting and diverting recyclable plastic waste from landfills and the environment. In the context of plastic waste in Pune city, it is estimated that 30,000 tons of plastic waste is collected and sent to recycling annually by the IRS (ESCAP 2018). A preliminary study of solid waste management in Delhi and Bangalore estimated that the IRS respectively saves municipal waste collection and disposal costs of approximately Rs 600,000 (13,700 USD/day) and prevents around 15% of waste from going to landfills (Sharholy et al. 2008). In Chennai, social enterprise Kabadiwalla Connect (KC) maps actors and dynamics within the informal waste management ecosystem in the city and highlights that leveraging existing informal infrastructure towards more efficient waste management systems has the potential to decrease the amount of plastic waste sent to landfills in Indian cities by 70% (Hande 2019). Beyond case study level estimates, official and accurate data on the scale and waste handling capacity of the informal recycling sector in India is limited and has mainly considered waste pickers at the lowest level of the informal recycling network, rather than holistically understanding the material flows and trade relationships across the informal recycling ecosystem, which beyond the collection, includes segregation, cleaning, trade, transportation, processing and pelleting.

Despite its evident societal contribution, the skills and recycling networks inherent in the informal recycling sector have predominantly been excluded when developing decentralized solutions to reduce plastic pollution. In some instances, the informal sector is seen as a problem rather than a solution for plastic pollution (IKHAPP Policy Brief series, March 2022). Within this narrative, formalization of the informal sector has often been promoted as the only viable way forward, but the processes and practical implications included in such transition have been varied and to a large extent, not well understood. From a policy perspective, formalization has been pursued in a top-down manner, by integrating informal waste pickers in municipal waste management systems, as door-to-door waste collectors or recycling workers at municipal waste management facilities (Aparcana 2017). Barriers to this transition may include a lack of economic incentives amongst waste pickers to become formalized and a lack of trust between informal and formal workers. Enabling measures may include working with waste picker organizations to ensure informal actors' interests are accounted for; economic and social incentives aimed towards the sector, including access to social security and applicable government insurance schemes, such as bank services, affordable loans health and education benefits; and confidence building measures between the informal and municipal waste management sectors. From a private sector perspective, recycling companies may as part of their corporate responsibility, partner with informal waste pickers and provide them with access to social services, such as identity cards, opening bank accounts for their salary, and information about available government insurance schemes. Several recycling companies have highlighted how this is economically beneficial for their company, as regulatory requirements and market-driven forces including consumer preferences increasingly demand value chain transparency and responsibly sourced materials, both when selling and exporting processed materials nationally and internationally.

There is limited guidance available for what informal recycling workers should do in practice despite some municipalities and companies prioritizing integrating them. While both the Solid Waste Management Rules (2016) and the amended Plastic Waste Management Rules (2018, 2021, 2022) recognize the need to identify and integrate waste pickers at a local level to account for the generation of recyclables collected informally, the regulatory frameworks do not provide any recommendations for conditions which can facilitate a just and sustainable transition. There is also a lack of recognition of the skills and broader network structures involved in the informal recycling sector, which hampers the sector's legitimacy in such a process.

Data gaps and an under recognized role of the informal sector in plastic waste management challenge quantification and efficient strategies for reducing plastic pollution across the value chain. These factors also contribute to increased livelihood insecurities and socio-economic marginalization of informal recycling workers, particularly those at the lowest levels of the recycling hierarchy are prone to economic insecurities (Shankar and Sahni 2019), health risks (Gill 2010; Toxics Link 2016, INOPOL, 2020), social exclusion, stigmatization and discrimination (Ferrontato and Torretta 2019; Chu and Michael 2019; Harriss-White 2020), exploitative working conditions (Gill 2010; Chikarmane 2014; Oates et al. 2018) and lack of access to social security and government insurance schemes (Chu and Michael 2018; Michael et al. 2019). Socio-economic livelihood insecurities are also disproportionately impacting women who tend to be over-represented in lower-earning and labour-intensive recycling activities, in which children often are involved from a young age contributing to perpetuated poverty across generations.

Data and knowledge generation can contribute to identifying and mitigating some of these livelihood insecurities. An increasing knowledge base on the informal recycling sector is fundamental to developing increasingly inclusive and sustainable (plastic) waste management solutions that facilitate improved end-of-life management options for plastic waste whilst promoting broader environmental, economic and social sustainable development goals (Singh 2020). Understanding different actors involved at different levels of the informal recycling chain is a departure point for recognizing where policy and practice may aid a sustainable inclusion of the informal recycling sector in formal (municipal and private sector) waste management.

5.4 Mapping (informal) plastic waste network and market mechanisms in selected regions

This chapter provides an overview of the different actors involved in informal recycling and the material flows and trade relationships between the different levels of the informal recycling chain. It is important here to holistically understand the informal recycling sector as an ecosystem beyond the traditional perception of the informal waste pickers as an isolated actor that live on the fringes of society with little value contribution. We highlight some of the complexities when discussing a just transition of the informal recycling sector, as well as capacities, skills, and opportunities inherent in existing recycling systems. Specific terms, sourcing of recyclables and trade relationships will naturally differ across geographical and socio-political contexts, both locally and regionally. However, when applying the same methodology as previous studies in Chennai (KC, 2017), our data indicates similarities in informal network structures in Surat and Vapi. Based on primary and secondary data, the following sections describe a typical informal recycling system, from collection to processing of recycled materials and thereby giving insights into leakages of these plastic wastes to the environment.

At the lowest level of the informal recycling network, are informal waste pickers and collectors, who are generally considered the most vulnerable to the inequitably distributed impacts of plastic waste, because these stakeholder groups work in direct contact with potentially hazardous substances without adequate waste handling training and access

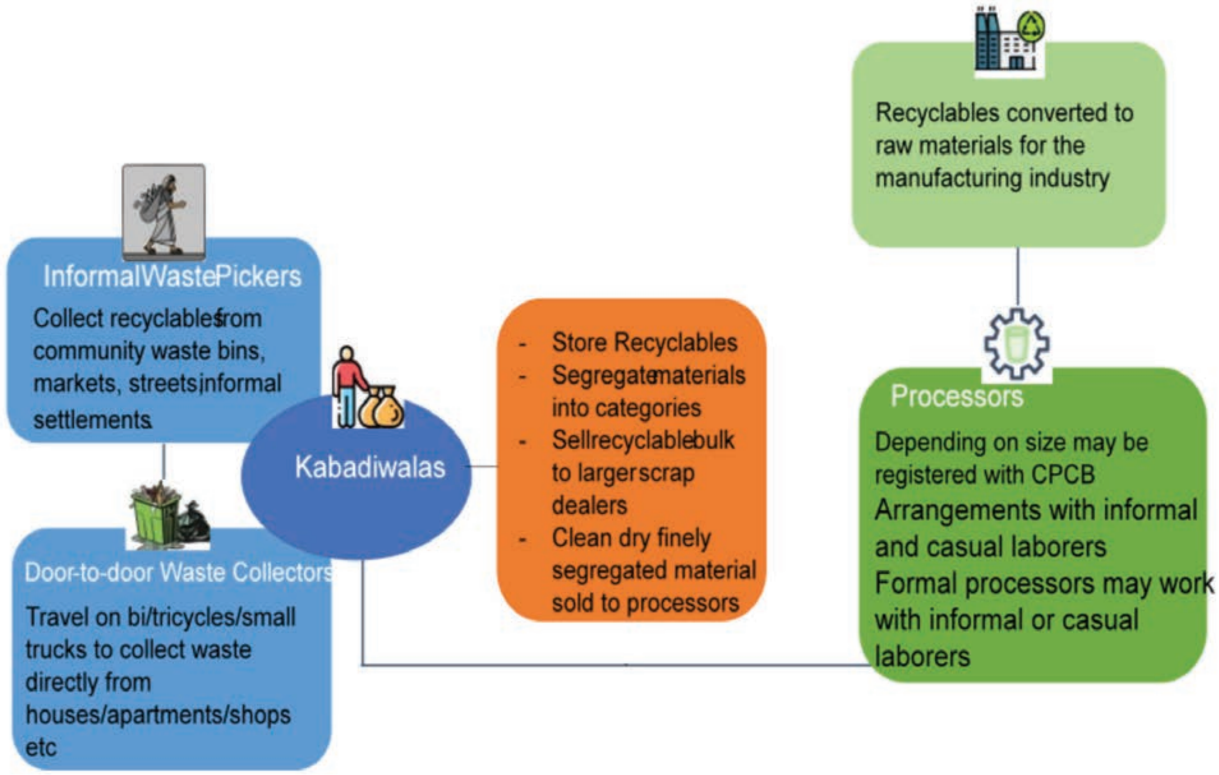


Figure 5.4.1. Informal recycling system (Kabadiwalla Connect)

to personal protective equipment (PPE) (Toxic Link 2016; ESCAP 2019). Economic insecurity and hazardous working conditions are thus particularly high at this stage of the informal recycling system, in addition to the broader systemic challenges associated with informal waste work (Gill 2010; UNEP et al. 2019).

Waste pickers, sometimes referred to as rag pickers, collect recyclables from public spaces including community waste bins, marketplaces, along streets, informal settlements and informal waste dumps. Waste pickers may sometimes also pay for access to pick waste from formal or privately operated landfills. Waste pickers typically travel by foot and have as such, relatively low spatial coverage, and collection capacity. At the same time, their access to high-value waste is limited as they manually segregate recyclables from mixed waste which may be contaminated and hazardous.

Door-to-door waste collectors also front at the lowest level of the informal recycling system but have a relatively higher degree of economic independence. Waste collectors, sometimes referred to as 'itinerant waste buyers' often travel on bi- or tricycles, sometimes small trucks, to collect waste directly from households, apartment complexes, shops, and businesses. They therefore have a relatively higher spatial coverage and collection capacity than waste pickers but require more capital investment to partake in the respective market. It differs whether waste collectors pay or get paid by waste generators to collect segregated recyclables.

Depending on the housing situation and collection capacity, both waste pickers and waste collectors may store recyclables at home before selling them in larger quantities to small junk shops, sometimes called *Kabadiwallas*, which represent the next level of the informal recycling system. Depending on their size, *Kabadiwallas* may handle different types of recyclables or specialize in one material, such as plastic. *Kabadiwallas* typically segregate materials into specific categories, for example, different types of plastic, before selling segregated recyclables in bulk to larger scrap dealers who are typically more specialized and have a larger storage capacity. From there, clean, dry, and finely segregated materials are typically sold to processors, who convert recyclables into raw materials for the manufacturing industry.

Depending on their size and machinery, processors may have registered with the Central Pollution Control Board, and may as such, be categorized as formal entities. However, they may have arrangements with informal and casual laborers working at the processing unit. At the same time, formal processors may have arrangements with informal or casual laborers working at the processing unit, illustrating a blurred and interdependent division between informal and formal actors at the different levels of the plastic recycling chain. Similarly, recycling workers employed in the municipal or private waste management sector may engage in the informal economy on the side for extra income. This challenges the view of the informal waste economy as an isolated process, which simply can be formalized by integrating waste pickers in municipal solid waste management systems. It also highlights how entrepreneurial and highly specialized individuals and micro-businesses have advanced to establish arguably efficient recycling infrastructures around wasted materials, which challenges traditional views of the informal sector as an unskilled, unorganized and inefficient entity (Haan et al. 1998; Moreno-Sanchez and Moldanodo 2006).

To better understand how existing skills and established networks in the informal recycling ecosystem can be utilized to reduce plastic pollution, knowledge and data generation on a local level are key. A stronger knowledge base will provide greater opportunities to identify and include relevant stakeholders throughout the informal value chain, recognize relevant measures to mitigate livelihood insecurities, ensure material flow transparency and traceability, and assess how to bridge pollution challenges and releases within formal and informal recycling practices.

Table 5.4.1: Overview of surveyed respondents at L0, L1 and L2 levels

Surat - 313 stakeholders:
L0 aggregator - 54 data points
L1 aggregator - 153 data points
L2 aggregator - 106 data points
Vapi - 88 stakeholders:
L0 aggregator - 40 data points
L1 aggregator - 18 data points
L2 aggregator - 30 data points

In the INOPOL study, carried out by Kabadiwalla Connect (KC) we employ the heuristic categories of L0, L1 and L2 as developed by KC (2017). The study was carried out through a sample survey in Surat and Vapi in 2022 and includes interviews through detailed questionnaires with 401 respondents who are located along various points of the waste management hierarchy. The heuristic categories in this hierarchy include the *L0 Level*, who are aggregators that collect waste material from dustbins or landfills and have zero input cost. They typically use transportation means such as a tricycle or carts, which they use to maximise their collection reach within a geographical area. They may also directly engage with households for collection and generally have no storage space of their own. *Level 1 Aggregators (L1)* — commonly known as kabadiwallas are retail oriented scrap aggregators that collect, store and minimally process waste material in dedicated shops sourced from L0 aggregators, as well as households or businesses. They concentrate in areas with the potential for high turnover of waste materials/recyclables for example, in residential areas, near industry or a landfill. In urban India, kabadiwallas typically buy many types of paper, glass, metal and plastic. This is then sold to L2 aggregators or to larger L1 aggregators on a weekly or biweekly basis. *Level 2 Aggregators (L2)* — consist of informal stakeholders that function similarly to a Material Recovery Facility (MRF). Their primary source of material is from Level 1 aggregators which they purchase in bulk. Their economic rationale is founded on their ability to store much larger volumes of recyclables, which they sell further in longer timeframes (e.g weekly or monthly cycles). Another characteristic is their larger degree of specialization in what material they deal with either with regards to segregation and/or pre-processing. Below, the summary findings from the extensive data are presented.

Thriving informal aggregator ecosystem in Surat and Vapi

In both locations, a thriving informal waste supply-chain was observed by KCs field team. It consisted of waste-pickers, who walked the streets or used a non-motorized tri-cycle to search for and collect recyclable post-consumer material, which they then sold to retail oriented scrap-shops present extensively within the administrative areas of Surat and Vapi. These scrap-shops then sold their material to more specialized larger aggregators (which in the case of Surat were found organized in clusters). It was further observed that the formal collection system was in fact selling recyclable waste salvaged from their collection route to Level 1 aggregators on their way to the transfer station or landfill. Figure 5.4.2. show the locations where aggregators were found and enumerated in both locations.

In both Surat and Vapi, it was observed that very minimal segregation was undertaken by waste-pickers during the time of scavenging with regards to plastics, and all material collected was stored and carried in a large non-woven sack and sold colloquially to the Level 1 aggregator as ‘mixed’ plastic.

Waste-pickers enumerated in the survey tended to collect on an average close to 1 ton of recyclable plastic every month, and sell their material for

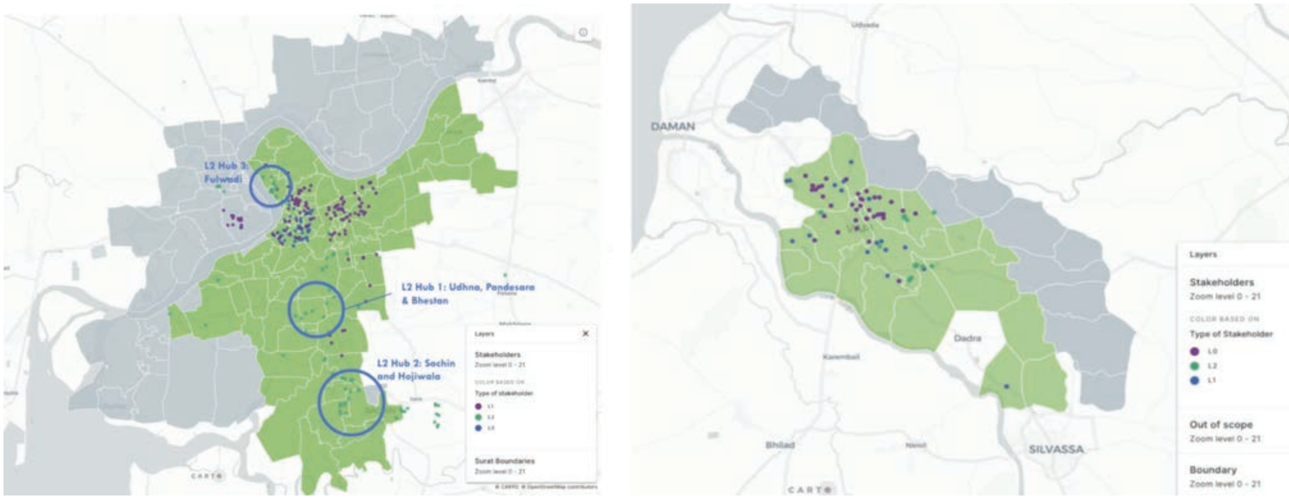


Figure 5.4.2. Map of Surat (left) and Vapi (right) with locations of aggregators

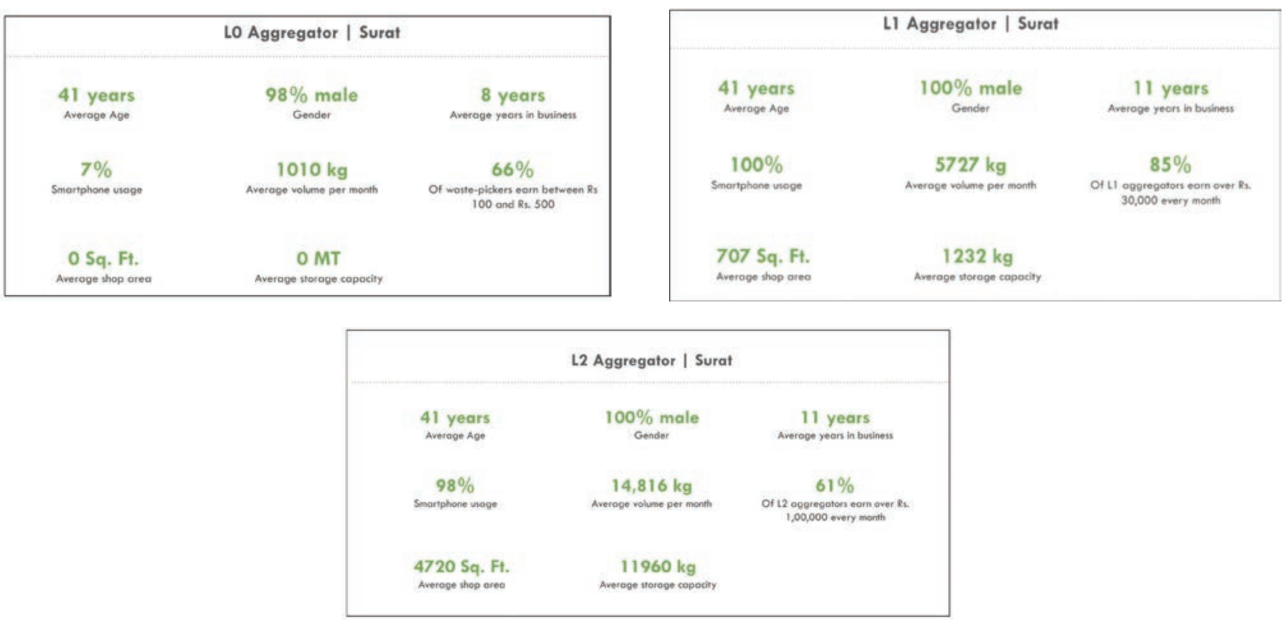


Figure 5.4.3. Data Snapshots across L0,L1 and L2 Levels in Surat

around INR 15 - 20 per KG. Two-thirds of the waste pickers surveyed in Surat reported making between INR 100 - 500 every day. Waste-pickers in both Surat and Vapi would collect material in one or two shifts every day. They would walk mainly through established routes where they would then scavenge for paper, plastic, glass and metal in bins, streets and on the banks of rivers and water bodies. Once this recyclable waste was collected, they would bring it back to a small scrap-shop in the city, which would pay them to receive this material. KC defines this type of small scrap-shop as a level 1 aggregator, and they are primarily set-up as independent businesses, which operate without a formal business license. They work closely with waste-pickers but also receive a significant amount of recyclable material from residents and local businesses in the area.

It was observed that level 1 aggregators in Surat on average collected and sold around 5 tons of plastic

L0 Aggregators

34
Average Age

9
Average years in business

572 kg/month
Average volume

L1 Aggregators

39
Average Age

12
Average years in business

2581 kg/month
Average volume

L2 Aggregators

45
Average Age

10
Average years in business

9857 kg/month
Average volume

Figure 5.4.4. Data Snapshots across L0,L1 and L2 Levels in Vapi

every month, and over 80% reported that they made over INR 30,000 in profits for the buying and selling of recyclables in the same time period. Unlike waste-pickers, 100% of respondents to the level 1 survey were using a smartphone. These businesses would typically buy many types of paper, plastic, glass and metal through the week, while simultaneously working to re-segregate the materials bought and aggregate them into higher volumes. They would then sell it in bulk to larger informal aggregators towards the end of the week, and receive a higher price for their efforts.

As mentioned, plastics bought as 'mixed' plastic from waste-pickers by level 1 aggregators would then be segregated into many types of categories. These materials were then sold to specialized larger aggregators, who would pre-process and store this material in much higher volumes ultimately selling to a formal off taker or to an informal processor.

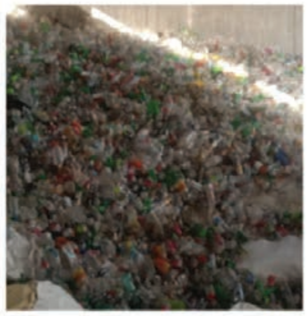
KC defines these types of large informal scrap-shops as level 2 aggregators, who are similarly independent businesses, and who operate in most cases without a business license.

In Surat, specific clusters that took advantage of industrial zoning as well as road connectivity and weigh-bridges were observed when examining where level 2 aggregators had set up shop. The difference in shop size and material specialization is of special note when comparing differences between level 1 and level 2 aggregators. It was observed that level 2 aggregators in Surat on average collected and sold close to 15 tons of plastic every month, and over 60% reported that they made over INR 1,00,000 in profits for the buying and selling of plastic in the same time period. Compared to level 1 aggregators, they had a much larger shop size, averaging around 4,700 square feet. In contrast, level 1 aggregators enumerated in Surat, reported having an average shop size of 700 square feet.

In Vapi, while the overall informal sector activity was much lower when compared to Surat, a similar distinction between aggregators was observed. However it was noted that only a handful of plastic material categories were being traded when compared to that of Surat.

PVC

Average Selling Price: Rs. 79.65



Terry

Average Selling Price: Rs. 23.82

Ramkada Mix

Average Selling Price: Rs. 31.30

LD

Average Selling Price: Rs. 65.29

Parachute

Average Selling Price: Rs. 49.89

Kadak

Average Selling Price: Rs. 17.86

Figure 5.4.5. Unique naming conventions observed for post-consumer plastic bought and sold in Surat and Vapi

Unique naming conventions observed for post-consumer plastic bought and sold in Surat and Vapi:

It was observed that the informal waste sector in Surat and Vapi had developed their own unique naming conventions when identifying, storing and sorting post-consumer plastic. For example, PET was colloquially called ‘Batla’ or ‘Terry’, and Rigid PP and PE were stored together referred to as ‘Ramakada’. The table below provides a detailed listing of major material handled, average price sold and unique naming conventions used by level 2 aggregators in Surat. Apart from PET and rigid PP and PE, significant volumes of PVC, LDPE and ABS were also seen to be collected.

High informal recovery of PET observed in neighborhoods:

PET was noted to have a very high recovery rate when considering waste generation volumes in Surat and Vapi — in relation to the collection rates by level 1 aggregators operating in the same neighborhoods. Post-consumer PET recovery in India is primarily undertaken for the manufacturing of polyester yarn by large formal processors, and due to clear demands by these off takers, is widely collected by level 0, level 1 and level 2 aggregators.

An assessment of PET recovery in Surat’s central zone by level 1 aggregators operating within its administrative boundary revealed a collection rate of close to 87%. KC undertook a census style mapping of level 1s in this administrative area, and it was found that there were 48 such scrap-shops recovering a total of 22.5 tons of PET every month. PP and PE on the other hand was collected in much smaller volumes (only 7.2%) when considering the amount that is generated in the central zone. One reason for this could be due to the absence of large off-takers in India. The collection requirements of PP and PE along with low value plastics to meet Extended Producer Responsibility (EPR) targets could represent an exciting opportunity for providing increased incomes and improved livelihood opportunities if it were to be collected through this extensive level 0, level 1 and level 2 network. For example, if the collection rates for these materials were developed to mirror the recovery rates of PET currently, it would present a win-win situation for stakeholders in both the formal and informal system in Surat and Vapi.

Conclusion

The field work and survey assessments on informal aggregators and waste-pickers revealed the existence of an active supply-chain working to collect large volumes of post-consumer recyclable waste in Surat and Vapi. It is important to note that the informal sector in these areas was observed to be the most important method of recyclable waste collection — supporting the municipality in diverting significant amounts of plastic waste away from rivers and the landfill.

However, a lack of accurate baseline data and poor consensus on the roles and potential of different stakeholders that operate in these informal waste networks in urban India hamper the ability of policy makers, the private sector and municipal authorities to develop inclusive and effective recycling strategies.

It is recommended that an active development of the informal waste sector baselines for all of India's tier 1, tier 2 and tier 3 cities takes place. This would provide stakeholders in the formal system the data needed to build inclusive recycling strategies that support livelihood development and integration of the informal sector — while helping to divert plastic waste away from the environment i.e water bodies, rivers and landfills.

As the demand for efficient and cost-effective strategies for post-consumer plastic collection and diversion grows in Indian cities, the informal sector could well provide the formal system with the infrastructure needed for the recovery, storage and transport of this material at scale

5.5 Plastics-Persistent Organic Pollutants (POPs) health interlinkages

Plastics are used in various ways and inevitably cross paths with POPs during their lifecycle. During the production of plastics, some of the chemical additives are POPs themselves. During use, plastics come in contact with POPs, and can absorb them onto their surface, acting as a vector. Plastics in the dump yard waste stream originate from households, institutions, and commercial establishments, and may interact with and accumulate POPs at any stage of production, usage, or disposal. Open burning is a major source of POPs emission, in both gaseous and particulate forms. Incomplete or complete combustion of polymeric materials results in release of Polychlorinated dibenzodioxins and dibenzofurans (PCDD/Fs) and Dioxin like-POPS (dl-POPs) in Indian cities.

Microplastics have become prevalent in the most remote regions, transported over long ranges by atmospheric and oceanic circulation, and ingested by organisms of critical trophic levels in oceanic ecosystems causing negative health and environmental impacts. Riverine/marine plastic litter is a cause for concern, given the potential for the transfer and bioaccumulation of POPs in a range of species upon ingestion, which may incur a range of negative health effects.

5.5.1 Health impacts associated with the open burning and mismanagement of plastic waste

Uncontrolled burning of plastic waste adversely affects local air quality and is a major human health risk, both for occupational workers dealing with waste and the wider public. Conventional representations have commonly placed the blame of open burning on the informal waste pickers (Rouse 2006) and on low levels of awareness amongst the poorer populations. However, these are some of the most vulnerable societal groups who face direct exposure to the hazardous emissions caused by open burning of plastic waste: Dioxin, furans, and other pollutants released during the open burning for disposal increase the risk of heart diseases and may cause respiratory ailments such as asthma and emphysema, and cause rashes, nausea or headaches, and damages the nervous system. Scientific evidence on potential harm to human health from open burning plastic waste has been linked with various groups of substance emissions: brominated flame retardants; phthalates; potentially toxic elements; dioxins and related compounds; bisphenol A; particulate matter; and polycyclic aromatic hydrocarbons. Table 5.5.1. presents a list of chemical compounds generated from burning of polyvinylchloride and its associated harmful effects.

Assessments have indicated significant risks of harm to waste pickers working closely with waste without protective equipment and under limited occupational health and safety standards, and residents of informal settlements (Velis and Cook 2021), where waste collection infrastructure is scarce, and open and uncontrolled burning has become an established self-management approach for the 2 billion humans that receive no solid waste collection services (Wilson et al. 2015). Many of the most affected

Table 5.5.1. Compounds generated from burning of polyvinylchloride and their harmful effects (Nagy and Kuti, 2016)

Compound	Harmful Health effect(s)
Acetaldehyde	Damages the nervous system, causing lesions.
Acetone	Irritates the eyes, the respiratory tract.
Benzaldehyde	Irritates the eyes, skin, respiratory system, limits brain function.
Benzole	Carcinogenic, adversely effects the bone marrow, the liver, the immune system.
Formaldehyde	Serious eye damage, carcinogenic, may cause pulmonary oedema.
Phosgene	Corrosive to the eyes, skin and respiratory organs.
Polychlorinated dibenzo-dioxin	Carcinogenic, irritates the skin, eyes and respiratory system. It damages the circulatory, digestive and nervous system, liver, bone marrow.
Polychlorinated dibenzofuran	Irritates the eyes and the respiratory system, causes asthma.
Hydrochloric acid	Corrosive to the eyes, the skin and the respiratory tract.
Salicyl-aldehyde	Irritates the eyes, the skin and the respiratory tract. It can also affect the central nervous system.
Toluene	Irritates the eyes and the respiratory tract, can cause depression.
Xylene	Irritates the eyes. It can also affect the central nervous system, reduces the level of consciousness and impairs learning ability.
Propylene	Damages the central nervous system by lowering of consciousness.
Vinyl chloride	Carcinogenic, irritating to eyes, skin and respiratory system. Effect on the central nervous system, liver, spleen, blood-forming organs.

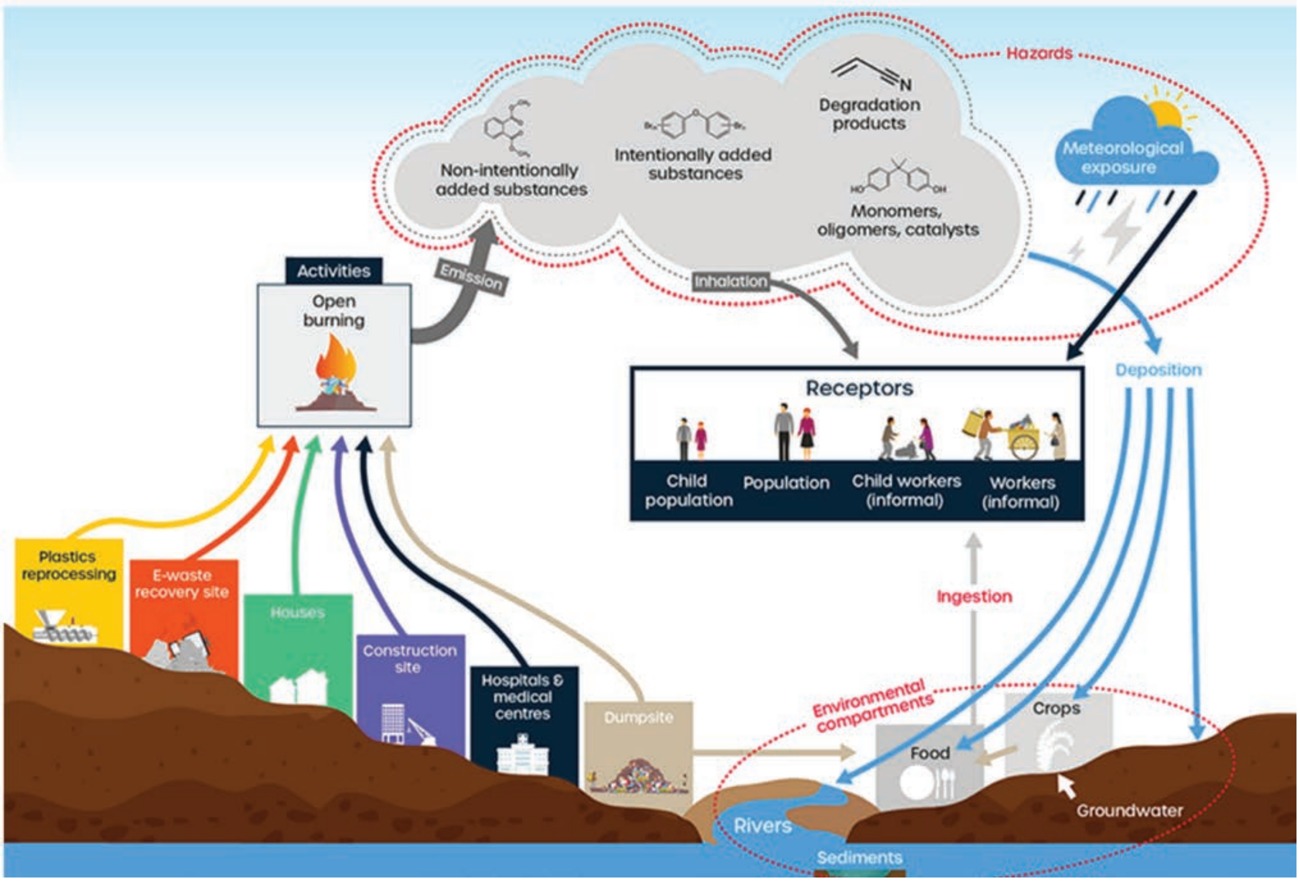


Figure 5.5.1. Hazardous effects of Plastic Waste Management through open and uncontrolled burning (Reprinted with permission from Velis and Cook 2021. Copyright 2021 American Chemical Society.)

individuals are also amongst the world's poorest, who work or live in close proximity to waste fires which have been deliberately or accidentally ignited (Ferranto and Torretta 2019) and have few options to sustain emission exposure.

Open burning is not a result of informal recycling activities or marginalized communities, but a broader systemic challenge which must be addressed through measures aimed at improving the reach of waste collection infrastructure and building financial and structural capacities to manage waste in marginalized communities, coupled with awareness raising and education of the hazardous impacts of uncontrolled burning and more sustainable and feasible management alternatives. Although the human health risks caused by open burning emissions is high, it remains a substantially under-researched subject and thus necessary research interventions must be made (Velis and Cook 2021). Also, based on the recommendations of the Basel and Stockholm Conventions, best available technologies (BAT) should be adapted for India to prevent contamination and lessen impacts on human health and the environment.

Chapter 6

REVIEW OF BEST AVAILABLE PLASTIC WASTE MANAGEMENT PRACTICES (INTERNATIONAL, NATIONAL AND LOCAL-LEVEL EXPERIENCES)

6.1 International perspectives

The resumed fifth session of the United Nations Environment Assembly (UNEA-5.2), which took place from 28th February to 2nd March 2022, concluded with the passing of 14 resolutions to strengthen actions for nature to achieve the sustainable development goals (UNEP 2022). A significant outcome was the agreement to establish an Intergovernmental Negotiation Committee (INC) with the mandate to forge an international legally binding agreement to end plastic pollution. Another key and related resolution supported the establishment of a comprehensive and ambitious science policy panel on the sound management of chemicals, waste and pollution prevention. Against this backdrop, it is becoming critical to adapt plastic waste management practices and policies towards increasingly circular and sustainable solutions, to be prepared for the forthcoming international negotiations and regulatory developments. The following sections provide contemporary international perspectives on some of the key concepts, strategies, and considerations which can support the transitions laying ahead.

6.1.1 Circular economy and zero waste strategies

Over the past decades, the discourse around municipal waste management has progressed from a linear system depositing waste in landfills, towards greater awareness of systemic changes that improves resource use and reduces waste across the lifecycle of products (Wagner 2022). Linear systems heavily rely on virgin raw materials, energy consumption, land for waste disposal, and causes pollution from production processes and mismanagement of waste (EMF 2015). In contrast, the circular economy is a closed and regenerative loop, in which resources, materials and products remains in the economy at the highest utility and value for as long as possible, while waste generation is minimized by formulation waste and hazardous products (EMF 2016). Applying the circular economy concept in practice involves reusing, repairing and recycling products and materials, and repurposing waste from one industrial process as resources in another (Preston et al. 2019). Moving towards circularity is particularly emphasized in relation to plastic waste, aiming to improve the economic viability of recycling and reusing plastics, reduce leakages of plastics in natural and marine environments, and decouple plastic production from fossil-fuel feedstock, while embracing renewable feedstock (EMF 2016).

Transitioning towards an increasingly circular economy can be particularly challenging in emerging economies, where formal waste management structures and institutional capacities are scarce (Preston et al. 2019). Structural and economic barriers to adopting circular economy practices may include existing production infrastructure and high investment costs, interdependent production and supply chains, lack of transition support for small and medium sized enterprises, uncompetitive circular products, lack of implementation and monitoring capacity, unfavourable regulatory environments, and lack of consumer awareness (Barra et al. 2018 p.12). Regulatory support to foster innovation, increase in the competitiveness of circular models, and facilitate demand for circular plastic products may contribute to overcome these barriers, supported by encouraging changes in societal behaviour amongst the private sector and the public (Ranta et al. 2018). Circular economy concepts may also be better aligned with existing policy priorities in developing countries, supported by investments needed for transitioning to the circular economy, while the global circular economy agenda may promote inclusive partnerships to catalyse systemic change (Preston et al. 2019).

However, it must also be acknowledged that many high-income countries, typically recognized as having effective waste collection and segregation systems, exports waste earmarked for recycling overseas, often to lower-income countries which tend to have less stringent environmental and health policies and relatively inadequate waste management infrastructures (Brooks et al. 2018). The global waste trade thus contributes to increase the negative environmental and social externalities related to plastic waste management, which must be accounted for in sustainable and circular solutions. In response, the novel "Small Circles" concept advocates the need to manage waste within the smaller geographical area of where waste originates, to reduce negative externalities, improve transparency, and boost social benefits (Havas et al. 2022).

The Zero Waste concept has evolved as a related concept alongside the emerging discourses around the circular economy, refers to "the conservation of all resources by means of responsible production, consumption, reuse and recovery of products, packaging and materials without burning and with no discharges to land, water, or air, that threaten the environment or human health" (ZWIA 2018). The Zero Waste movement provides zero-waste toolkits and guidelines for reducing resources use and waste generation, and identifies seven steps in solid waste management, ranging from least to most preferable, including unacceptable practices (incineration and waste-to-energy), residual management (biological treatment and stabilized landfilling), material recovery, recycle/compost, reuse, reduce, rethink/ redesign (Zero Waste Europe). In India, the zero-waste concept has been championed by amongst others, the Indian Citizen Consumer and Civic Action Group, who produced an extensive guidebook to urban decentralized waste management (Shekhar and Kapivali 2020).

6.1.2 Regulations on single-use plastic products (SUPPs)

Since the United Nations Environmental Assembly called for national action plans to tackle plastic pollution and marine litter in 2017, an increasing number of policies have been implemented across the world to reduce plastic littering and improve plastic waste management (Syberg 2021). A range of strategies has been adopted at national level targeting end-of-life plastic waste management (such as China, Vietnam, Malaysia, banning imports, mandating deposit refunds, product take-back, recycled content quotas); consumers and retailers (for example in Rwanda, Europe, India, Canada, by imposing bans, taxes and fees on the import and use of single-use plastics); and producers (France, for example, by extended producer responsibility fees, bans on specific plastic products such as microbeads) (Barrowclough and Birkbeck 2022).

One of the most commonly observed regulatory means is bans on certain single-use plastic products (SUPPs), particularly single-use plastic (SUP) bags. As of July 2018, 127 countries had imposed regulations on SUP bags, either through retailers, imports, manufacturing fees, or consumer charges (UNEP 2018). A growing number of states are also regulating a broader group of SUPPs, typically cups, plates straws and cutlery. For example, The EU Single-use Plastic Directive (Directive (EU) 2019/904) banned ten categories of SUPPs from June 2021 and imposed regulations on several more categories, while the Indian Plastic Waste Management Rules (PWMR 2021) stipulated a stepwise approach to ban 17 problematic SUPP categories by mid-2022.

It has been challenging to assess the efficiency and success of SUPP bans (Dikgang, Leiman and Visser 2012; Conti et al. 2021). The long-term prospects for regulatory bans to reduce consumption of SUP bags is to date uncertain (Karasik et al. 2020) and depends on availability of feasible alternatives, monitoring and enforcement capacities, and public awareness (Xanthos and Walker 2017). Extended producer responsibility (EPR) mechanisms may offer an alternative for products which lack appropriate, affordable and accessible alternatives. EPR is based on the on the idea that the producers should be held responsible for the waste generated from the products they enter into a market (the "polluter-pays" principle) (OECD 2021). EPR has the potential to increase the recovery and recycling of products, reduce contamination and develop markets for materials that are difficult to recycle (Cassel et al. 2020).

6.1.3 Lifecycle approach towards microplastics regulation

Microplastics may be defined as small plastic particles that are either specifically engineered or derived through degradation and fragmentation of larger plastic items. The term plastic typically includes synthetic polymers, including those produced from both hydrocarbons and other, natural materials. The European Chemicals Agency (ECHA) categorizes microplastics as extremely persistent and argue that the irreversibility of leakages and increasing stocks necessitate cost-effective action, despite unclear evidence on the risks posed by microplastics to human and environmental health (ECHA 2020; GESAMP 2015).

To date, microplastics have typically been addressed as a component of plastic pollution regulations and measures. One recent exception is California State's Microplastics Strategy (California Ocean Protection Council 2022). The strategy takes a two-pronged approach, categorizing measures as "Solutions" and "Science to Inform Future Action". The solutions address immediate actions to mitigate microplastics pollution, such as pollution prevention at source, pathways interventions and education initiatives targeting the public and industries. The science strategy identifies future research priorities; addressing monitoring, risk, sources and pathways prioritization, and new solutions appropriate for the Californian context.

Releases of microplastics take place during the entire lifecycle of plastic products: from production and transportation of plastic pellets (Karlson et al. 2018), to leakages during the manufacture of plastic products, during use (car tires, textile fibres, microbeads, plasticulture) and in the end of use phase (Paruta et al., 2022). Measures must be designed accordingly and consider national variability in dominant sources and pathways (Boucher and Friot 2017). The EU has recently imposed bans and restrictions on commonly littered products which break into microplastics, including oxo-degradable plastics (Directive (EU) 2019/904). Microbeads in cosmetics have been banned in Canada, France, Italy, the Netherlands, New Zealand, Republic of Korea, Sweden, the United Kingdom (UK) and the United States (US) (Conti et al. 2021); while guidelines for stormwater management to intercept microplastics are in place in Sweden and Norway (FanpLESStic-sea 2019). Few states utilise financial measures, though Lithuania has introduced environmental pollution taxes on microplastics sources such as packaging and car tires (FanpLESStic-sea 2019). However, these measures and strategies are relatively recent, and their impacts and effectiveness remain to be examined.

Within a rapidly changing regulatory environment, both nationally and internationally, it is key that efforts to reduce plastic pollution is grounded in scientific research. While lessons can be learned by drawing on best international practices, local and national knowledge generation must support priorities and decision-making to ensure solutions are implementable in practice and avoid unintended socio-economic and environmental consequences of well-intended pollution reduction measures.

6.2 Material aspects: Bioplastics

KEY POINTS

- Bioplastics (biobased, biodegradable and compostable plastics) are briefly described.
- Degradation of bioplastics is highly affected by their physical and chemical structures.
- Current market impacts of biodegradable plastics are also highlighted.

A bioplastic is a plastic material that is either biobased, biodegradable, or possesses both qualities (European Bioplastics, n.d.). The phrase 'biobased' refers to a substance or product that is derived entirely or partially from biomass (i.e., plants) (Tokiwa et al., 2009). Bioplastics can be made from different biomass sources, such as maize, sugarcane, or cellulose. Plastic that degrades as a result of biological activity is referred to as biodegradable plastic. This differs from compostable plastics. It is critical to understand the fundamental difference between biodegradable plastics and compostable plastics (Figure 6.2.1.). Biodegradation is a term that refers to a physical or chemical change in a substance caused by biological activity. Composting is a man-made process, whereas biodegradation occurs naturally. Composting is an accelerated biodegradation process that takes place under controlled and optimal conditions. Hence, the phrases biodegradable and compostable may be used interchangeably in some contexts, but are not synonymous (Goel et al., 2021). The fact that a given bioplastic is biodegradable does not imply that all bioplastics are biodegradable. The term bioplastic should be communicated with caution based on the lack of universal awareness of the facets of the definition.

In recent years, there has been a lot of interest in biodegradable polymers made from renewable resources. This renewed interest stems from global environmental awareness and the problem of fossil fuel depletion. Biopolymer research and development, as well as production, have been at an all-time high for several years.

Poly(lactic acid) (PLA), polyglycolic acid (PGA), polycaprolactone (PCL), polyhydroxybutyrate (PHB), poly(3-hydroxy valerate) and poly(butylene adipate-co-terephthalate) (PBAT) are the main biopolymers currently garnering interest. The utilisation of renewable natural resources such as lignocellulosic fibres, starch, and other materials to reinforce these biopolymers and composites has improved their performance characteristics for many end-use applications.

Degradation is an end-of-life process that can be classified into two categories: abiotic degradation and biodegradation (Leja et al., 2010). Abiotic degradation, which is a purely non-biological process, encompasses a variety of processes such as oxidation, photolysis, and thermal degradation. Biodegradation, on the other hand, occurs through the action of micro-organisms or enzymes present in the recipient environment digesting the material and breaking down the polymer chain.

The carbon substrates present in the material are used by micro-organisms in biodegradation, and this process is also known as metabolism by micro-organisms such as bacteria and fungus. The temperature of the recipient environment has been a key element in controlling micro-organism

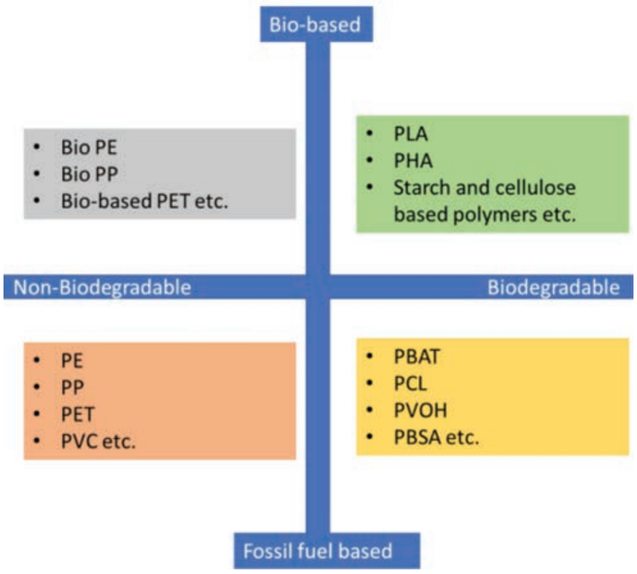


Figure 6.2.1. Types of bioplastics.

(*Source*: Adapted from(Basavegowda & Baek, 2021) & (Lisitsyn et al., 2021))

activity. The nitrogen concentration and pH value have an impact on micro-organism activity and, hence, the rate of biodegradation. The attribute of hydrophobicity is another important factor that influences biodegradation.

Aerobic and anaerobic biodegradation are two types of biodegradation (Figure 6.2.2.). Aerobic biodegradation occurs in the presence of oxygen and produces CO_2, H_2O, and biomass as a by-product, whereas anaerobic degradation occurs in the absence of oxygen and produces CH_4 as well as CO_2, H_2O, biomass, and residue.

The rate of biodegradation may be tracked by looking at changes in, for example, the molecular weight of the plastic, functional groups, or the chemical structure. The rate of CO_2 released in aerobic degradation and the rate of CO_2+CH_4 released in anaerobic degradation can be used to indicate the ultimate degradation rate.

Medicine, packaging, agriculture, and the automobile industry represent the main users of biopolymers thus far (Patwary et al., 2020 & Andreopoulos et al., 1994). In 2019, global bioplastics production capacity reached 2.11 million tonnes, with biodegradable plastics accounting for 55.5% (approximately 1.17 million tonnes). Over the next 4 years, output is expected to increase by 14%.

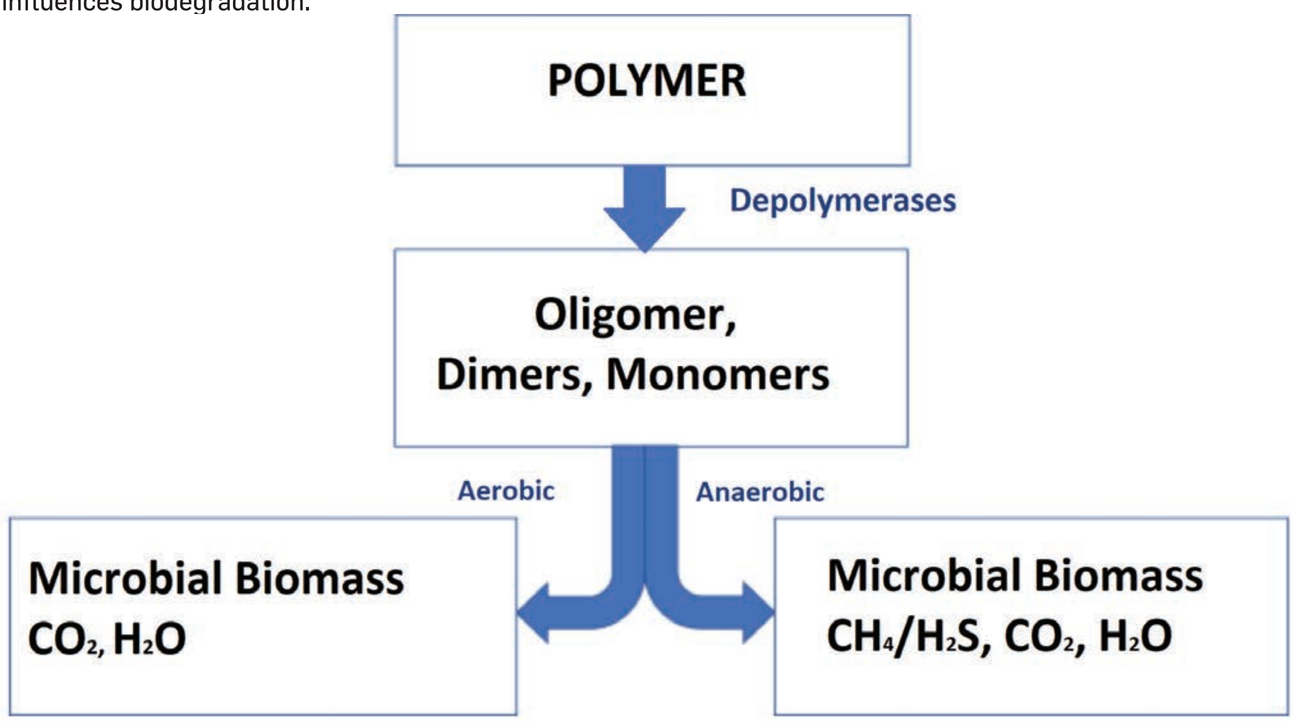


Figure 6.2.2. Degradation of bioplastics.

(*Source*: Adapted from (Gu & Mitchell, 2006) & (Pathak & Navneet, 2017))

Domestic production capacity for biodegradable polymers, specifically PLA, PBAT, PHA/PHB, and PBS, has yet to be established in India. Biodegradable polymers, on the other hand, are distributed by firms such as M/s Natur Tech India Pvt. Ltd, Chennai, M/s Green Diamnz Solutions, M/s Earthsoul India Pvt. Ltd, and M/s KPS Consultants & Impex Pvt Ltd. Environmental awareness campaigns, easy availability of feedstock, and government support may also lead to an increase in the bioplastic sector in India.

While bioplastics are often portrayed as preferable to conventional plastics, there is a lack of knowledge about the fate or impacts of these materials if discarded into the environment. Some bioplastics, such as bio-based plastics, represent more environmentally friendly options based on the use of biomass in place of fossil fuels; however, if they enter the environment, they may still persist across long time scales similar to conventional plastics produced from fossil fuels. Biodegradable and compostable plastics typically undergo certification before they can be labelled as such. This demonstrates that the materials degrade under certain conditions and that the residues do not impart acute toxicity on relevant organisms following some standardised ecotoxicological tests. However, if these plastics become micro- or macro-plastic pollution, they may enter an environment with conditions that do not meet those required for degradation. In this case, they may be persistent and will not break down. This is particularly relevant for compostable plastics that require industrial composting conditions to degrade: conditions that do not occur naturally. Compostable plastics that enter the environment will, therefore, not degrade. Further research is needed to better define the persistence of different biopolymers in different relevant environments, as well as the long-term risks of microplastic residues of bioplastics on a range of ecosystems. While this knowledge gap persists, careful communication is required to ensure proper use of different bioplastics for different applications.

6.3 National and local perspectives (Indian Case Studies)

The case studies presented here are from a recent publication by NITI Aayog and the Centre for Science and Environment (CSE) that highlights the best practices in 10 different thematic areas of waste management across 28 cities in 15 states (Atin Biswas, Subhasish Parida et al., 2021)

6.3.1 Panaji

Through the persistent efforts of the Corporation of the City of Panaji (CCP) over the last 15 years at improving methods and involving citizens in the process, Panaji – the capital city of the State of Goa has been successful in managing segregation, sorting, and recycling of its waste. A zero-waste and zero-landfill strategy has been established by implementing decentralized waste management and processing waste at the source. In light of the limited space available in the city and the high volume of waste generated, local city officials explored waste management methods, including innovative technologies, continuous information, education, and communication (IEC), waste treatment at the source, and waste reduction, among others. As a result of public awareness campaigns, the city has made excellent progress toward promoting waste segregation at the source. In 2021, the city introduced 16-way segregation at the source, as well as a variety of waste management technologies and activities. Mini sorting stations, conveyor belt segregation, customized vehicle designs, improved hazardous waste handling, promotion of eco-friendly products, and specially designed street bins have all contributed substantially to the success of this city. In addition to the improvement in waste management, the sales of recovered commodities generate revenue, increasing worker incomes.

6.3.2 Indore

It is due to the well-planned communication strategy, the active use of social media, adherence to laws, including the imposition of fines, and the effective implementation of waste management chains that Indore has been ranked consistently since 2017 for consecutive years. Indore's waste management system remained similar to the rest of the cities until 2015 when committed leadership motivated and effective stakeholder participation that led to a significant transformation in the waste management chain. The city has a well-developed communication strategy in place to encourage extensive behavioral changes in citizens to adopt segregation right at the source. This was followed by the implementation of a robust monitoring system and the adoption of a set of bylaws that ensured sound enforcement of the laws. Following segregation, the city conducted research to determine the population and amount of waste generated in every ward. This information was used to develop a route plan. Based on these estimates, the authorities were able to designate a certain number of vehicles and workers to meet the needs of their waste collection program. In the Indian waste management sector, Indore emerged as a leader and number one city in effectively segregating waste at source (100% segregation), effective public participation, and efficient administration.

6.3.3 Bengaluru

While Bengaluru (Bangalore) is still working toward effective waste management, the city's efforts to integrate Information Communication Technologies (ICT) into solid waste management are commendable. A variety of ICT solutions are used by the Bruhat Bengaluru Mahanagara Palike (BBMP) to monitor waste management techniques and synchronize coordination among waste management concessionaires in 2020. These include a radio-frequency identification (RFID) based attendance system and geotagging of collection routes, to address the issue of monitoring waste management techniques. In addition, Ezetap, a smartphone application, monitors garbage-vulnerable sites and imposes penalties for violations. Bangalore's door-to-door waste pickup increased from 65% to 100% with these technological interventions. All payments are transparently determined by the number of trips made and the amount of waste collected and carried. Using fixed routes and RFID makes the system uncomplicated, smooth, and mess-free, which leads to lower fuel and vehicle operating costs. The implementation of technological solutions has led to accountability, service assurance, hassle-free garbage collection, mess-free and a reduced incidence of fleet mismanagement (from around 280 per year to zero) all of which support the solid waste management in the city Additionally, data-driven IEC initiatives have improved behavioural change and citizen participation.

6.3.4 Ambikapur

The "Zero Waste Model Ambikapur" has eliminated dustbins, dumping yards, and landfills in the city. Ambikapur's waste management revolution has largely been attributed to the intervention of the local administration and women's self-help groups inspired by the Garbage Clinic Model, which has enabled the city to achieve 100% waste segregation, collection, and processing. Waste is separated into 20 inorganic fractions by secondary segregation, then into 156 categories by tertiary segregation at the Solid and Liquid Resource Management Centre (SLRM). A legacy waste dumpsite has been cleared and now functions as a waste recycling facility. In addition, AMC has successfully reduced its land acquisition costs by reclaiming encroached land worth Rs 25 crore. Segregation at source has enabled the corporation to earn Rs. 84.81 lakhs from recycling waste. Moreover, the SRLM model generated 623 green jobs without imposing a financial burden on the state. There are two sources of income for members of SHGs. The SHG members receive money from the sale of recyclables in addition to the Rs. 5000 paid by the AMC. Due to the decentralization of the waste management process, transportation costs have been reduced from Rs. 7.32 lakhs in June 2015 to Rs. 2.1 lakhs in October 2017. Through Mission Clean City, the Ambikapur Model has been sustained and replicated in 165 ULBs across Chhattisgarh, and as a result, Chhattisgarh has been named India's cleanest State for three consecutive years in 2019, 2020, and 2021.

6.3.5 Kumbakonam

Kumbakonam established a resource recovery facility in response to the state government's ban on plastic in 2019. Plastics that were not recyclable were converted into refuse-derived fuel and sold to cement manufacturers for co-processing, while recyclable fractions were recycled. Kumbakonam has experimented with both decentralized biodegradable waste management and a healthy blend of centralized processing via a biomethanation plant. To become a bin-free and garbage-free village, Kumbakonam has implemented a holistic waste management model with decentralized waste management and source segregation. Using biomining technology, the municipality successfully reclaimed a dumpsite in the city. The segregation level in the city peaked at 80 percent, a record high in Tamil Nadu State.

Chapter 7

RECOMMENDATIONS AND WAYS FORWARD

7.1 Summary of recommendations

Although there is no single solution for enhancing plastic waste management, the development of legislative frameworks in India has made significant progress in recent years. Below are some recommendations across the thematic areas of sampling and monitoring, management tools, and political and socio-economic dimensions to assist the regulations for enhanced plastic waste management in Gujarat State.

7.1.1 Sampling and monitoring recommendations for litter and microplastics

- **Monitoring plastic litter fluxes -** Monitoring plastic litter fluxes should account for spatial and temporal differences. River mouth monitoring, estimates ocean release from different catchments. Monitoring various segments of a river system can aid the identification of hotspots and key sources. Seasonal variations can also be identified through year-round monitoring. Multiple methods are recommended, including routine visual observation at several points along the river width and citizen science by providing standardized protocols for data collection. Floatable and non-floatable components could be captured by nets placed on bridges or boats in the downstream area. To get representative samples, it is important to determine the location of the net deployment(s) based on visual observation results.
- **Monitoring plastic litter accumulation -** Pre and post-monsoon monitoring are recommended to assess plastic accumulation and removal in the Tapi and Daman Ganga rivers, these can also estimate potential peaks in plastic litter flux during flood or flushing events. Modeling suggests that plastic litter transport triggered by flooding is large. Adapted OSPAR method may be followed for monitoring to survey visible plastic litter (UNEP, 2020). Additionally, investigating inputs to the river environment during the dry season, including stranded plastics and littering will enhance identification of optimal pollution reduction measures.
- **Monitoring of microplastic fluxes -** With nets, microplastic sampling is simplified, less infrastructure is required, and river water does not need to be drained. During the INOPOL project, nets were deployed with smaller mesh sizes (maximum 300 m) to catch microlitter from waterways where water flowed freely. The type of nets and the length of deployment may be decided depending on the degree of litter in the river flux in the specific river.
- **Monitoring microplastic accumulation -** For a better understanding of microplastic accumulation and remobilization during high flows, riverbed sediment samples may be taken,

including submerged and exposed areas of the channel. Collection methods may be comparable for both types of samples, for example, corers or grab samplers. River sediment accumulation patterns may be monitored before and after monsoons. Investigating the potential role of Ukai and Madhuban dams in interrupting microplastic flux downstream is also relevant data to understand the fate and pathways of such pollution (UNEP, 2020).

7.1.2 Management tools

- **Hydrological and vegetation-related information for improvement of the model -** Various hydrological conditions, obtained in various seasons and at various sites across catchments is crucial for validating the macroplastic model. The dynamics in other river compartments may be investigated. A comparison of contrasted model calibrations showed that the accumulation of plastic in vegetation would increase future plastic exports. The origin and age of riverine plastics could be investigated using an equivalent approach to beach litter deep dives.
- **Long-term fate of the mismanaged plastics accumulated on land over the last decade -** such information is required to better appreciate the magnitude of mismanaged plastic stores on land and help in future clean ups. Assessing illegal dumping and burning sites is crucial information for improving management. Municipalities must continue to report the quantity and type of waste collected and processed, by both formal and informal activities. Data on plastic waste collected by the informal sector and its end-of-life fate are important. Modelling outputs would benefit from information on the location, size, and amount of waste in these infrastructures, enhancing its predictive power and analytical applicability.
- **Water reservoir management and water diversion in irrigation canals need to be considered -** To understand the plastic fluxes, implication of control measures, and assess effective control measures, knowledge about reservoir management and water diversion is important. Such data may be fed into modeling, yielding a more complete understanding of plastic litter behavior, fate, and environmental implication.

7.1.3 Political and Socio-economic Dimensions

- **Effective Measures to support the Extended Producer Responsibility (EPR) -** To reach the EPR targets of 70% for producers in 2022-23 and 100% in 2023-24, stringent implementation measures will be needed, along with enhanced stakeholder cooperation and informal sector engagement. Furthermore, a greater focus on segregating waste at source is required. The type of plastic to be targeted also may be addressed as a priority in the EPR. It is also necessary to improve the waste management infrastructure in rural areas to ensure the collection, scientific processing, and disposal of plastic waste. At the city level, low-value plastics such as MLP need to be collected and processed adequately. The guidelines on EPR for plastic packaging (PWM, 2022) mandate minimum levels of recycling of plastic packaging and the use of recycled plastic content. However, challenges persist in relation to collection and recycling infrastructure, financial capacities, and awareness to implement EPR effectively
- **Increased awareness for eliminating certain Single-Use Plastic Products (SUPPs), implementing the provisions set by the PWM Rules -** Public awareness can contribute to facilitating the implementation of policies, hence there is a need for sustained and innovative public awareness programs to promote behavioural changes for the effective implementation of waste management policy.
- **Promote reuse and re-purposing strategies -** Currently community-led initiatives have

primarily focused on encouraging source segregation, recycling, plastic waste to energy recovery, and repurposing waste plastics for building materials. However, downcycling practices, such as waste to energy recovery processes, are not the best options for strengthening the circular economy and should be avoided, in particular for recyclable material. Reuse and re-purposing should be prioritised to reduce waste at source.

- **Supporting and sustaining waste management strategies:** Segregate waste at source, and using MRFs for sorting dry wastes (including plastic waste) into fractions suitable for recycling or processing into value-added items, thereby minimizing the number of plastics and dry waste disposed of in landfills or in the environment.

  There is considerable uncertainty around the fate, cost-effectiveness, and management of alternative materials to plastic. Moving ahead with their large-scale adoption and promotion requires careful reading of recent research findings, supporting new research efforts, and also consideration of the potential adverse impact bioplastic may have in polluting existing waste streams and causing unintended environmental harm. Similarly, they need to be adaptable to local climatic contexts.

- **Integrating the Informal Recycling Sector:** Recognising the contribution of the IRS and its workers in waste management while formalizing their working conditions are important steps to improve labour conditions and welfare. Informal waste workers can, for example, also be allocated quotas in Material Recovery Facilities (MRFs). A stronger knowledge base of the precise composition, quantities, and value creation of the IRS will be useful for policymakers to propose effective measures that supplement the waste management system in municipalities. Baselines for Tier 1,2 and 3 cities are thus needed. Materials flows can then be more transparently assessed become traceable, and pollution issues tackled in a better way. Part of the primary research conducted by the project contributed to advance knowledge of the potential of the informal recycling sector as an integral part of the plastics value chain and an important element of improving end-of-life management. The informal sector generates significant social, economic, and environmental benefits by collecting and diverting recyclable plastic waste from landfills and the environment. It is key to ensure that informal actors' interests are taken into consideration and that formalization is pursued in an inclusive manner to promote a just transition toward ending plastic pollution.

- **Focus on occupational health and safety in the waste collection and segregation sector-** Given the vulnerable status of workers (formal or informal) in the waste management sector, it is important to enable and link the workers with social security provisions (e.g government schemes, CSR) that emphasize health and well-being but also support training, education, and 'upskilling'. Similarly, systems to enable access to credit, finance and insurance will contribute to reducing vulnerabilities and improving quality of life.

- **Reduce health impacts of plastic burning and hazardous wastes** - Building financial and structural capacities for waste management, raising awareness and education about the hazards associated with uncontrolled burning, and providing more sustainable and feasible waste management alternatives can improve waste management. Gram Panchayats and Urban Local Bodies should monitor, report, and intervene during plastic burning activities. More effective management of garbage-vulnerable sites could also be achieved through the use of ICT and the enforcement of penalties on violators, as highlighted from the case study of Bengaluru in the NITI Aayog and the Centre for Science and Environment (CSE) report highlighting the best practices across 28 cities in 15 states.

- **Regular reviews, monitoring, and training -** The States and urban local bodies are to regularly review and monitor the effective implementation of policies. Prioritizing training and capacity building can lead to a long-term change in behavior to support the reduction in the use of plastics, segregation, recycling of low-value plastics, such as bags, sachets, etc, and support in the overall management of plastics. Prioritization of regular training programmes by the industry and government will be beneficial.

  It may be useful to draw on the challenges, achievements, and lessons learned from the case studies illustrating best practices on zero landfill strategies, source segregation, the use of information communication and technology (ICT), enhanced stakeholder participation, improved communication techniques, awareness generation, and holistic waste management practices, to improving waste management systems in cities and rural areas. It is key that practices are implemented with consideration of local contexts.

7.2 Impediments and opportunities: Stakeholder consultations perspectives

Summary of concerns and challenges

The following section discusses the concerns and challenges that need to be considered when developing policies, which are derived from extensive stakeholder consultations with government officials, non-governmental organizations, industry professionals, and sector experts. These challenges have been detailed under the following classifications of regulatory, institutional, and technical.

Regulatory

- There exists a disconnect between framing and implementation of the PWM byelaws at the local level. The frequency of the current laws being amended is high, and it can be challenging for local bodies to keep track of them often leading to a gap in understanding and poor implementation.
- The recent amendment in PWM rules does not include modalities for integrating the informal sector. The EPR may propose some modifications, such as a requirement (for registration) that the waste management agencies hire a minimum number of waste pickers as part of their workforce.
- With regard to EPR, the policy needs to address priorities with regard to the type of plastic to be targeted (notably low-value plastics).
- There is a need for drafting a state-level single-use plastic phase-out action plan incorporating priorities streams of waste and the phase-out time-lines.
- Emphasis at the city level must be laid on ensuring the collection and processing of low-value plastic such as MLP.
- Considering the extensive usage of plastic waste, the waste management infrastructure in rural areas needs to be improved to ensure collection, scientific processing, and disposal.
- Since the government is investing in MRFs, there should be a directive guiding the integration of the informal sector. A quota for waste pickers can also be allocated in Material Recovery Facilities (MRFs) or dry waste collection centers. In an effort to formalize the informal sector, by involving at least 25% of the workforce at the MRFs and waste pickers could account for a fair share of the ground workforce for Waste Management firms in the EPR market.
- A lack of transparency in the ULB's selection process of agencies for implementation of PWM hinders adequate regulation

Institutional

- One of the keys to better waste management is consumer awareness, and it requires time and constant efforts to change habits that will support proper post-consumer waste management. Littering is an issue of concern that leads to the escape of waste from the formal waste collection system. Industries must ensure that consumers are aware of how post-consumer waste should be handled by actively engaging in awareness activities in collaboration with urban local bodies.
- Need for prioritization of Training and Capacity building and behaviour change activities. While there is an increase in recycling, low-value plastics, such as bags, sachets, etc., are not even collected. Appropriate behaviour changes need to be made for enhancing the collection and recycling of low-value plastics. Training and capacity building needs to be prioritized and conducted on a regular basis by the Government and Industries.
- Strengthening of IEC activities: A well-designed IEC program should constantly generate greater awareness through information shared with stakeholders, training, and capacity building that in turn will bring about behavioural changes, the absence of which can lead to failure of potential solutions and infrastructure.
- In order to achieve a long-term solution, industries and municipalities must work together in co-processing, a proven method of managing non-recyclable dry stream wastes. Cost-sharing and input waste quality are among the challenges that need to be addressed.
- While the lack of infrastructure in rural areas is a disadvantage, there is also resistance seen in several villages to set up waste management facilities catering to multiple villages. One of the reasons is that they are unwilling to accept waste from other villages.
- Lack of financial incentive to consumers for segregation. Such incentives can improve waste collection. Incentives are needed for low-value plastic (Types 5,6,7). Currently, only types 1-4 have value, and types 5-7 have no buyers. The concept of minimum support price (MSP) may be considered in the PWM sector
- The GST rules have been a great barrier for the PWM sector. Initially, the GST was 5% and then it was revised to 18% which severely impacts the informal sector whose transactions are in cash.

Technical

- A substantial expansion of the existing infrastructure of MRFs and recycling facilities will be necessary to accommodate low-value plastics.
- Lack of efforts to incentivize the collection of low-value plastics which have no inherent market value.
- Low-value plastic collection and scientific processing is an issue of concern under EPR.
- Standardizing packaging and improving the design to increase recyclability are examples of possible measures that needs to be taken for identifying the opportunities related to improving Design for the Environment.
- Despite Gujarat having large cement industries, the non-acceptance of Grade 3 RDFs is a challenge.
- Approximately 12-15% of Gujarat's plastic is non-recyclable, while 7% of it is inert.
- There exist large gaps in the collection of plastic waste. Currently, 80-90 MT of plastic waste is collected, in comparison with a target of 220 MT.
- Similarly, in comparison with the amount of waste generated, there is lesser recycling facilities.
- Almost 80% of all plastic waste generated by the State is recyclable and is collected, whilst the remaining 10 to 15%, which is non-recyclable, is sent to cement kilns for co-processing and the remainder is disposed off in landfills.

The following opportunities were elaborated

Regulatory

- According to the latest amendment in PWM rules, Extended Producer Responsibility (EPR) and its associated targets can be achieved via Producers (P) and Brand Owners (BO), a crucial step towards the polluter pays principle.
- According to the official from GPCB, a phase-out plan for SUP in 2022 is in progress and is expected to be ready soon
- Gujarat has MRF facilities, owned by the local governments, and their operations and maintenance are handled by local waste management agencies. The plastic waste is sent to these MRFs in order to be co-processed since it is the most environmentally sustainable solution for low-value plastics.
- GPCB has been conducting raids on stockists, distributors, and manufacturers to ensure compliance. There is a very well-organized group of people who monitors the movement of GPCB vehicles and warn each other of movement on WhatsApp and Telegram groups.
- The informal sector is a readily available and trained force that has demonstrated ways in which it can be integrated with PWM through training, recognition, and fair remuneration.
- The "Gobardhan Yojna" is being implemented in rural areas of the state. Gobar (cow dung) is purchased by two biogas plants in Gujarat at Rs.1.00/kg, the three by-products produced being compost, bio-gas & liquid waste, which have agricultural applications.

Institutional

- Industries support: A number of industries are making environmental-friendly packaging available in response to the ban on single-use plastics. By the end of the decade, these industries aim to use 100% recycled or bio-based plastics.
- The state and the region, in particular, have an adequate network of informal workers who provide services for segregation and recycling of dry waste. Surat city has also acknowledged the importance of integrating informal sector workers within a formalized solid waste management workforce.
- Surat has a well-established modality for the collection of user fees with good coverage and efficiency of collection.
- Surat city engages in ensuring scientific end-of-life management of plastic such as used in the construction of roads. SMC identifies during the annual planning process, the lengths of road (in km) to be constructed utilizing plastic waste and ensures appropriate amounts are handed over to contractors.
- Success story of Panjim, Goa under the banner *Shop with your waste* encourages cities to implement measures for encouraging the collection of recyclable plastics through the use of incentive mechanisms such as the barter system where groceries are exchanged for recyclable materials.

7.3 Strengthening science-policy-society interphase: Capacity building, awareness and research

The Ministry of Environment, Forests and Climate Change (MoEFCC) introduced Plastic Waste (Management and Handling) Rules in 2011, introducing Extended Producer Responsibility (EPR) for the first time in India (MoEFCC 2016). Later, these were replaced by the Plastic Waste Management (PWM) Rules, 2016, and complemented by the Solid Waste Management (SWM) Rules, 2016 (MoEFCC). The two policies paved the way for the current waste system in India. These were strengthened by guidelines for dealing with waste, such as the Guidelines for Segregation, Collection, and Disposal of Plastic Waste in 2017 and the Guidelines for Co-processing of Plastic Waste in Cement Kilns in 2018 (CPCB 2016, CPCB 2017).

Subsequently, MoEFCC released the draft Uniform Framework for Extended Producer Responsibility (Under Plastic Waste Management Rules 2016) on June 26, 2020. Extended Producer Responsibility (EPR) is the producer's responsibility to facilitate a reverse collection mechanism and recycling of end-of-life, post-consumer waste. The Draft rules offer three options to producers:

- Pay a fee into a central corpus that would be spent towards managing the plastic waste;
- Participate in and pay for establishing producer responsibility organizations (PROs) to collect and manage post-consumer plastic waste; and
- Buy credits from a system that would be established to balance the plastic waste they generate.

These policy processes have been informed by scientific knowledge as well as social dynamics. As for example, a recent study by CIPET along with CPCB on estimating plastic waste in Indian cities shows that plastic wastes account for approximately 8-10% of municipal solid waste generated in the cities. While evaluating this distribution, it may seem that in terms of volume this is not much. However, low-value plastic waste is usually not recovered for recycling or energy recovery and leaks into the environment.

In order to manufacture certain packaging products, a registration from the respective State Pollution Control Board (SPCB) is required prior to the commencement of production, which is only granted if an action plan for setting up a PWM system is presented (Ministry of Housing and Urban Affairs 2019). The MoEFCC has also proposed a draft National Resource Efficiency Policy 2019, which aims to streamline the efficient use of resources particularly in priority areas such as the plastic sector, while minimizing negative environmental impacts.

At the state level of regulation on plastic waste, governmental agencies frequently refer to national policies and legislation for the regulation of upstream processes in the plastic value chain. Several states were determined by the Indian Government as Petroleum, Chemical, and Petrochemical Investment Regions (PCPIRs) to promote industrial development. To date, four of these PCPIRs were approved in Andhra Pradesh (Vishakhapatnam), Gujarat (Dahej), Odisha (Paradeep), and Tamil Nadu (Cuddalore, and Nagapattinam). In these PCPIRs, waste and effluent management, the protection of green areas, the implementation of environmental impact assessments as well as the development of appropriate infrastructure to address environmental, health, and safety concerns are regulated under the responsibility of the state authorities (Government of Andhra Pradesh 2013, FICCI 2019).

Although EPR has gained a foothold in the Indian waste management sector since the first introduction of the PWM Rules in 2011, its implementation mechanism was unclear to plastic waste producers, urban local bodies, and state regulators. As a result of the PWM rules of 2016, all companies using plastic packaging are required to register as "producers" or "brand owners" (Saahas Zero Waste 2020). Moreover, PWM Rules require producers and brand owners to register with SPCBs and CPCBs if they operate in more than one state, and to submit an EPR plan. The PWM Rules prohibit putting products on the market without presenting an EPR plan (MoEFCC 2016). As a result of insufficient progress, the GOI notified the Uniform EPR Framework in 2020 to further guide the implementation at the State and city levels. In June 2020, the MoEFCC published its long-awaited draft uniform framework for EPR. Since PWM in the urban and rural settings is part of MSW management, the institutional set-up for effective management of plastic waste will mostly coincide with the practices for solid waste management under the purview of MoHUA. Considering the rising concerns linked to plastic, additional nodal institutions/bodies could be set up in order to tackle the issue of mismanaged plastic by working across different ministries. Notably, the Draft National Resource Efficiency Policy from 2019 appears to take

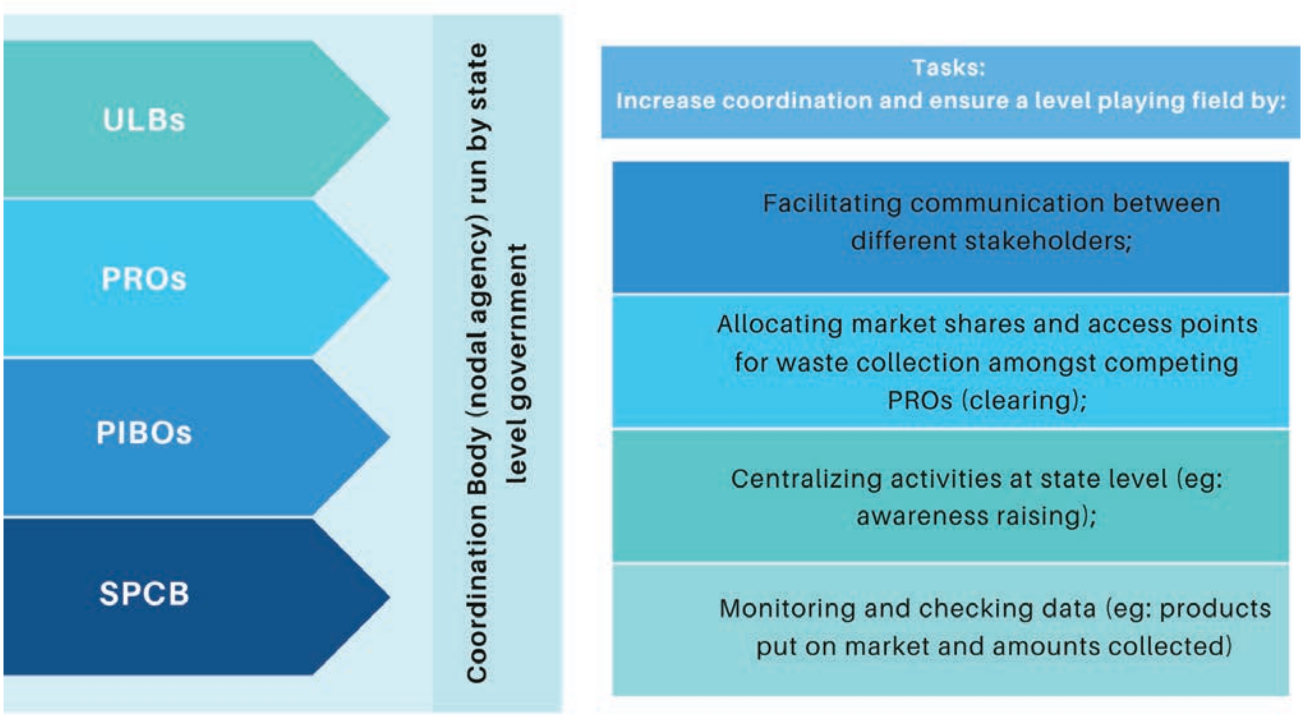


Figure 7.3.1. Potential additional tasks to be carried out by state-level coordination bodies.
(*Source*: TERI, 2021)

steps in this direction as it foresees the creation of a National Resource Efficiency Authority (NREA) with a core working group housed in the MoEFCC and a group of representatives from different ministries, state/union territory, and other stakeholders. In addition, we suggest to further strengthen horizontal coordination mechanisms on waste management through the existing Inter-State Council (ISC). A typical institutional association of different agencies to improve PWM is suggested below.

An effective EPR can be implemented through a partnership between policy-science and society. The recently published Standard Operating Procedures (SOP) for EPR implementation have highlighted the need for a body with similar responsibilities (CPCB 2021). The SOP has assigned the responsibility of the state government in this regard to nominate such a state-level nodal agency for the purpose of coordination to ensure that the entire state including rural local bodies, town *panchayats*, and cantonment boards are covered under the EPR framework.

Awareness among the various stakeholders especially the users and generators of plastic waste are equally important to ensure the efficient collection and recycling of plastic waste. The Urban Local Bodies (ULBs) and *Gram Panchayats* need to play an important role in this field and can be supported by academia and think tanks in designing and organizing such programs.

In light of the geophysical and socio-economic diversity of Indian states and cities, programs must be developed and implemented in a systematic manner that is responsive to local conditions. For example, in the case of *Stree Mukti Sanghatana*[2] in Mumbai, the use of innovative media such as plays, literature, and poster exhibitions were successful measures in widening the outreach to areas with low literacy rates and supporting formalization efforts.

[2] A community-based organization involved in waste management.

After collection, transportation and interim storage, mixed and dry waste must increasingly be channelled towards Material Recovery Facilities (MRFs) in order to be sorted and allow for effective recovery of different types of plastics. It is imperative that ULBs expand MRF infrastructure and adapt their operations to include informal workers since solid waste generation (including plastics) is likely to increase in the foreseeable future. Integrating the informal sector requires adequate upskilling and capacity building. Technology should be integrated with existing capabilities to deliver scalable solutions for society in accordance with environmental health and safety norms. In order to ensure recycling funds are used effectively and there is no duplication of effort, a joint responsibility model between industry-producer responsibility organizations (PROs) and ULB needs to be co-created at the city level. The joint responsibility model should also monitor EPR implementation, which consistently remains a weak link in policy implementation.

Research needs at the national level include addressing the issue of plastic pollution in lake and river, clean-up action plans and missions. The States need to take up plastic waste leakage source assessment, hotspot assessment, and pathways of flows to water bodies and coastal water as applicable to be able to identify weaknesses in the current waste management system and accordingly plan for plugging the gaps. Additionally, State PCBs need to work towards standardization of methodologies for plastics sampling, identification, assessments, analysis, and waste flow monitoring. A national EPR fund should also be used to fund research on upstream measures like design for the environment (minimum hazardous materials), recycling design, and introduction of alternative packaging materials, especially as single-use plastics are phased out from 1st July 2022.

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ANNEXURE

Annexure 1: Sampling location details

Phase-I Sampling-December 2020		
S.NO	**Sample ID**	**Location**
Matrix : Surface water		Latitude & Longitude
1	DG-U-1A	20.263458, 72.990382
2	DG-U-1B	20.263458, 72.990382
3	DG-U-2	20.268229, 72.988571
4	DG-U-3A	20.275632, 72.983993
5	DG-U-3B	20.275632, 72.983993
6	DG-U-4	20.276158, 72.983047
7	DG-M-1	20.340157, 72.911734
8	DG-M-2	20.339713, 72.910998
9	DG-M-3	20.339914, 72.910249
10	DG-M-4A	20.339910, 72.909590
11	DG-M-4B	20.371480, 72.881397
12	DG-M-5	20.371480, 72.881397
13	DG-D-1	20.410910, 72.834249
14	DG-D-2	20.411445, 72.832091
15	DG-D-3	20.411723, 72.832034
16	DG-D-4	20.411369, 72.828365
17	DG-DS-GW	20.410381, 72.834314
18	TP-U-1	21.284529, 72.951519
19	TP-M-1	21.221273, 72.866489
20	TP-M-2	21.178804, 72.792199
21	TP-M-3	21.145330, 72.746384
22	TP-D-1	21.130732, 72.708321
23	TP-D-2A	21.105825, 72.703320
24	TP-D-2B	21.105825, 72.703320
25	TP-D-2C	21.105825, 72.703320

Total no. of samples: 25

DG-U= Daman Ganga Upstream; DG-M =Daman Ganga Midstream; DG-D = Daman Ganga Downstream

TP-U= Tapi Upstream; TP-M=Tapi Midstream; TP-D=Tapi Downstream

Phase-II Sampling-September 2021		
S.NO	Sample ID	Location
Matrix: Surface water		Latitude & Longitude
1	DG- U_W-S1-01	20.216667, 73.026667
2	DG-U_W-S1-02	20.21671, 73.02631
3	DG - U_W-S1-03	20.21665, 73.02712
4	DG - U_W-S2-01	20.25641, 72.99072
5	DG - U_W-S2-02	20.25621, 72.99103
6	DG - U_W-S2-03	20.25666, 72.99083
7	DG - U_W-S2-04	20.25821, 72.99028
8	DG - D_W-S1-01	20.41083, 72.83416
9	DG - D_W-S1-2A	20.41027, 72.83611
10	DG - D_W-S1-2B	20.41055, 72.83611
11	DG - D_W-S2-01	20.41222, 72.83138
12	DG - D_W-S2-02	20.41222, 72.83166
13	TP- U_W-S1-01	21.2701, 73.50536
14	TP-U_W-S1-02	21.27095, 73.50564
15	TP - U_W-S1-03	21.27052, 73.50344
16	TP - U_W-S2-01	21.26934, 73.49989
17	TP - U_W-S2-02	21.26913, 73.50004
18	TP- U_W-S2-03	21.26934, 73.49907
19	TP - D_W-S1-01	21.07937, 72.70686
20	TP - D_W-S1-02	21.07857, 72.70787
21	TP - D_W-S1-03	21.07744, 72.70951
22	TP - D_W-S2-01	21.16075, 72.76721
23	TP - D_W-S2-02	21.16104, 72.76723
24	TP - DW-S3-01	21.17911, 72.79216
Matrix	Debris	
1	DG- Ddeb -S1-01	20.41089, 72.83407

Total no. of samples: 24

DG- U_W = Daman Ganga Upstream , DG - DW Daman Ganga Downstream , TP- U_W = Tapi Upstream TP - D_W = Tapi Downstream ; DG- Ddeb= Daman Ganga Debri

Annexure 2: Evolution of PWM policies in India (Kapur Bakshi et al., 2021)

Policy	Year	Description
Environment (Protection) Act	1986	Authorizes the central government to protect and improve environmental quality, control and reduce pollution from all sources, and prohibit or restrict the setting and /or operation of any industrial facility on environmental grounds.
Guidelines for Recycling of Plastics	1998	Describes types of wastes, classification of recycling, and steps involved in the recycling process
Recycled Plastics Manufacturing and Usage Rules	1999, 2002, 2003	Rules have laid down provisions for the manufacturing, usage, End of Life (EoL) management; criteria for manufacturing plastic carry bags and containers. Amendments (2002; 2003) provide specifications for virgin and recycled plastic manufacturing, extend definition of vendor, and mandate registration and authorization for manufacturers, production, sale, or trade for plastic packaging.
Solid Waste (Management and Handling) Rules	2000, 2016	Declared responsibilities of authorities on national, state, and municipal levels. New rules have mandated source segregation of waste and event organizers, Resident Welfare Associations RWAs, market associations, gated communities, institutions, and Special Economic Zone (SEZ) have been assigned the responsibility
Plastic Waste (Management and Handling) Rules	2011	Rules put ban on use of plastic materials in sachets for storing, packing, or selling *gutkha*, tobacco and pan masala
Food Safety and Standards Regulations	2011	It lays down general requirements for packaging and labelling
Plastic Waste Management (Amendment) Rules	2016, 2018	Requires producers/brand owners who introduce plastic carry bags, multi-layered plastic sachets, pouches, and packaging into the marketplace to submit an EPR plan. The amended (2018) rules state that only those multi-layered plastics (MLPs) will be phased out which are non-recyclable or non-energy recoverable or have no alternate use. Also there will be a central registration system for the registration of the producer/ importer/brand owner
Guidelines for disposal of thermoset plastic waste including: Sheet Moulding Compound /Fibre Reinforced Plastic (FRP)	2016	According to these guidelines, the most preferred option is minimization of use of Sheet Moulding Compound/FRP/ polycarbonate polymer products and promote the use of alternate material which are easily recyclable/reusable/ degradable
Guidelines for coprocessing of plastic waste in cement kilns	2016	Guidelines provide the protocol to be followed by different stakeholders and description of co-processing plastic waste in cement kilns

Environment Protection Act (control of non-biodegradable garbage)	2016	Prevent throwing or depositing non-biodegradable garbage in public drains, roads, and places open to public view and protect the environment from being polluted by such garbage and for matters connected therewith or incidental there to
Consolidated guidelines for segregation, collection, and disposal of plastic waste	2017	Guidelines provide roles and responsibilities of different stakeholders in efficient plastic waste management and technologies for disposal of plastic wastes
Guidelines for the disposal of non-recyclable fraction (multi-layered) plastic waste	2018	Guidelines provide the source of non-recyclable plastic waste and management of non-recyclable plastic waste
Prohibition of import of PET flakes	2019	GOI prohibits the import of PET bottle waste/scraps PET flakes made from used PET bottles, etc.
Guideline Document : Uniform Framework for Extended Producers Responsibility (Under Plastic Waste Management Rules, 2016)	2020	Mandate manufacturers to take responsibilities over materials used in their products beyond the sale-phase
Plastic Waste Management (Amendment) Rules	2022	Provide a framework to strengthen the circular economy of plastic packaging waste and promote alternatives to plastic

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