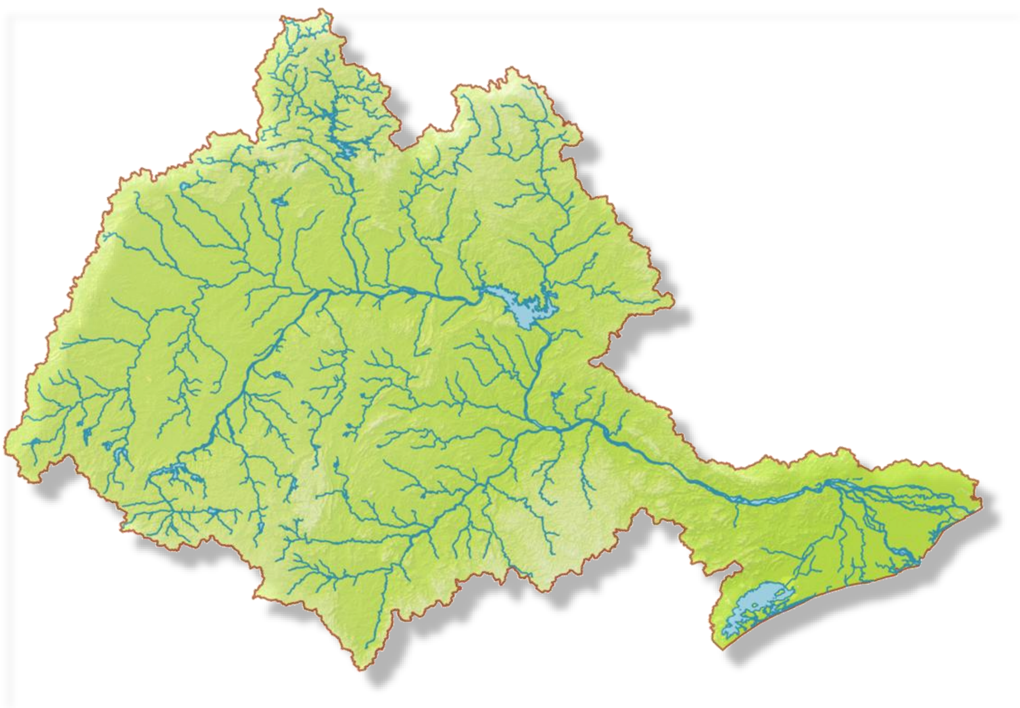
National River Conservation Directorate
Ministry of Jal Shakti,
Department of Water Resources,
River Development & Ganga Rejuvenation
Government of India

MANAGEMENT PLAN FOR INDUSTRIAL WASTEWATER



August 2026

Back of cover page

BLANK

MANAGEMENT PLAN FOR INDUSTRIAL WASTEWATER

Mahanadi River Basin

cMahanadi

cGanga

National River Conservation Directorate (NRCD)

The National River Conservation Directorate, functioning under the Department of Water Resources, River Development & Ganga Rejuvenation, and Ministry of Jal Shakti providing financial assistance to the State Government for conservation of rivers under the Centrally Sponsored Schemes of 'National River Conservation Plan (NRCP)'. National River Conservation Plan to the State Governments/ local bodies to set up infrastructure for pollution abatement of rivers in identified polluted river stretches based on proposals received from the State Governments/ local bodies.

www.nrcd.nic.in

Centres for Mahanadi River Basin Management Studies (cMahanadi)

The Centres for Mahanadi River Basin Management Studies (cMahanadi) is a Brain Trust dedicated to River Science and River Basin Management. Established in 2024 by NIT Raipur and NIT Rourkela, under the supervision of cGanga at IIT Kanpur, the center serves as a knowledge wing of the National River Conservation Directorate (NRCD). cMahanadi is committed to restoring and conserving the Mahanadi River and its resources through the collation of information and knowledge, research and development, planning, monitoring, education, advocacy, and stakeholder engagement.

www.cmahanadi.org

Centre for Ganga River Basin Management and Studies (cGanga)

cGanga is a think tank formed under the aegis of NMCG, and one of its stated objectives is to make India a world leader in river and water science. The Centre is headquartered at IIT Kanpur and has representation from most leading science and technological institutes of the country. cGanga's mandate is to serve as think-tank in implementation and dynamic evolution of Ganga River Basin Management Plan (GRBMP) prepared by the Consortium of 7 IITs. In addition to this, it is also responsible for introducing new technologies, innovations, and solutions into India.

www.cganga.org

Acknowledgment

This report is a comprehensive outcome of the project jointly executed by NIT Raipur (Lead Institute) and NIT Rourkela (Fellow Institute) under the supervision of cGanga at IIT Kanpur. It was submitted to the National River Conservation Directorate (NRCD) in 2024. We gratefully acknowledge the individuals who provided information and photographs for this report.

Team Members

NIT Raipur

Dr. Samir Bajpai, Coordinator

Dr. A. V. Ahirwar, Principal Investigator

Dr. Kshitij Upadhyay, Project Scientist

Dr. Amit Kumar Shukla, Project Scientist

NIT Rourkela

Dr. Kishanjit Kumar Khatua, Coordinator

Dr. Kakoli Karar Paul, Principal Investigator

Dr. Snigdha Sarita Mohapatra, Postdoc Fellow

Dr. Tinkle Das, Postdoc Fellow

Preface

In an era of unprecedented environmental change, understanding our rivers and their ecosystems has never been more critical. This report aims to provide a comprehensive overview of our rivers, highlighting their importance, current health, and the challenges they face. As we explore the various facets of river systems, we aim to equip readers with the knowledge necessary to appreciate and protect these vital waterways.

Throughout the following pages, you will find an in-depth analysis of the principles and practices that support healthy river ecosystems. Our team of experts has meticulously compiled data, case studies, and testimonials to illustrate the significant impact of rivers on both natural environments and human communities. By sharing these insights, we hope to inspire and empower our readers to engage in river conservation efforts.

This report is not merely a collection of statistics and theories; it is a call to action. We urge all stakeholders to recognize the value of our rivers and to take proactive steps to ensure their preservation. Whether you are an environmental professional, a policy maker, or simply someone who cares about our planet, this guide is designed to support you in your efforts to protect our rivers.

We extend our heartfelt gratitude to the numerous contributors who have generously shared their stories and expertise. Their invaluable input has enriched this report, making it a beacon of knowledge and a practical resource for all who read it. It is our hope that this report will serve as a catalyst for positive environmental action, fostering a culture of stewardship that benefits both current and future generations.

As you delve into this overview of our rivers, we invite you to embrace the opportunities and challenges that lie ahead. Together, we can ensure that our rivers continue to thrive and sustain life for generations to come.

Centre for Mahanadi River Basin
Management and Studies (cMahanadi)
NIT Raipur & NIT Rourkela

Contents

List of Figures

List of Tables

1. INTRODUCTION AND OBJECTIVES

1.1 Introduction

Water is a critical resource for industrial operations, and its availability, quality, and reliability directly influence industrial productivity and profitability. Industries depend heavily on water for a wide range of applications, including manufacturing processes, power generation, agriculture, mining, oil and gas production, and food processing. Industrial wastewater contains a variety of contaminants including suspended solids, organic matter, oils grease, heavy metals, chemicals and other hazardous substances. If this is discharged without treating can adversely affects the human health, aquatic life and regulatory compliance. Several industrial sectors are particularly water-intensive. The textile and paper industries consume large volumes of water during processing and finishing operations, while chemical, pharmaceutical, mining, and energy industries rely on water for cooling, extraction, separation, and reaction processes. Similarly, food and beverage industries require substantial water for washing, processing, and sanitation. These factors will lead to water scarcity therefore proper plan for industrial waste water management is required to sustain the planet. (UNESCO, 2024)

Effective industrial wastewater management is driven by regulatory compliance, environmental protection, public health concerns, and corporate sustainability goals. This report plan to outline the procedures responsibilities and control measures necessary to minimize environmental impacts, ensure compliance with applicable environmental laws, discharge standards and promote efficient water resource management this will emphasize in prevent pollution through source reduction, process optimization, water conservation, recycling and continuous monitoring of wastewater quality. The purpose of this report is to present an industrial wastewater management framework that outlines the procedures, responsibilities and control measures necessary to minimize environmental impacts, ensure compliance with applicable environmental legalize discharge standards and promote efficient water resource management. (UNEP, 2023; International Finance Corporation [IFC], 2020). 1.2 Objectives

The primary objectives of Industrial Wastewater Management Plan are:

- To identify major industrial sectors, wastewater generation patterns, treatment practices and environmental challenges for assessing the existing industrial wastewater management scenario.

- To determine the feasibility of shared wastewater treatment infrastructure and develop strategies for collective wastewater management to evaluate industrial clusters and common effluent treatment plant. (CETP)
- To develop a roadmap for Zero Liquid Discharge (ZLD) implementation by assessing technical and economic feasibility, identifying sector specific requirement and addressing gaps in achieving ZLD across industries.
- To strengthen hazardous waste and toxic liquid waste management by assessing treatment, storage, transportation and secure landfill requirements while recommending appropriate disposal and recovery strategies.
- To evaluate the performance of wastewater treatment facilities through real time monitoring systems, regular inspections, environmental surveillance, and data management by establishing a framework for continuous monitoring and compliance.
- To recommend policy and regulatory interventions by encourage resource recovery and water reuse by improving wastewater management practices, strengthen environmental compliance and support sustainable industrial development.
- To ensure compliance with national and state environmental regulations governing industrial effluent discharge, hazardous waste management and environmental protection.
- To provide an implementation framework with prioritized actions, institutional mechanism, monitoring indicators and capacity building measures to facilitate effective execution of the industrial wastewater management plan.

2. CLUSTER ANALYSIS

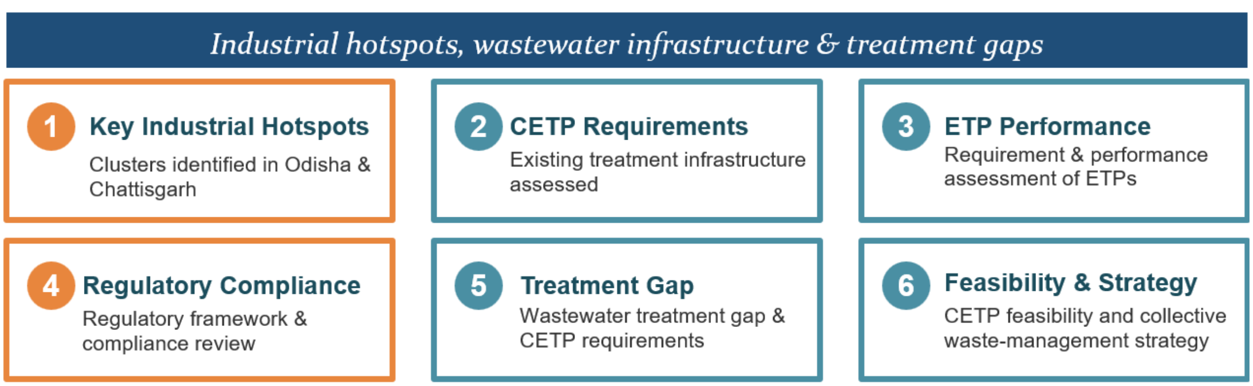


Figure 1. industrial cluster analysis and CETP requirements

Industrial cluster analysis is an important component of industrial wastewater management because the quantity and characteristics of wastewater are strongly influenced by the type, scale, density and spatial distribution of industries. A cluster-based approach enables industries with similar wastewater characteristics or located within a common drainage and conveyance network to be assessed collectively. It also helps in determining whether individual Effluent Treatment Plants (ETPs), Common Effluent Treatment Plants (CETPs), advanced treatment systems or Zero Liquid Discharge (ZLD) systems are technically and economically appropriate.

For the Mahanadi River Basin, cluster analysis is particularly important because industrial activities are distributed across several major industrial belts, including areas associated with power generation, aluminium, steel, mining, paper, chemical, fertilizer and petrochemical industries. These industrial activities may generate wastewater with substantially different characteristics, including organic matter, suspended solids, dissolved salts, oil and grease, nutrients, heavy metals and sector-specific toxic constituents. Therefore, a uniform wastewater-management strategy for the entire basin would not be appropriate.

Pany et al. (2023) applied Principal Component Analysis (PCA), Factor Analysis (FA), Cluster Analysis (CA) and Water Quality Index (WQI) to Mahanadi water-quality data and subsequently developed Artificial Neural Network (ANN) models for water-quality prediction. The study used data from six monitoring stations and 19 water-quality parameters for the period 2011–2019, demonstrating the usefulness of multivariate techniques for identifying influential water-quality parameters and supporting prediction of water-quality conditions (Pany et al., 2023).

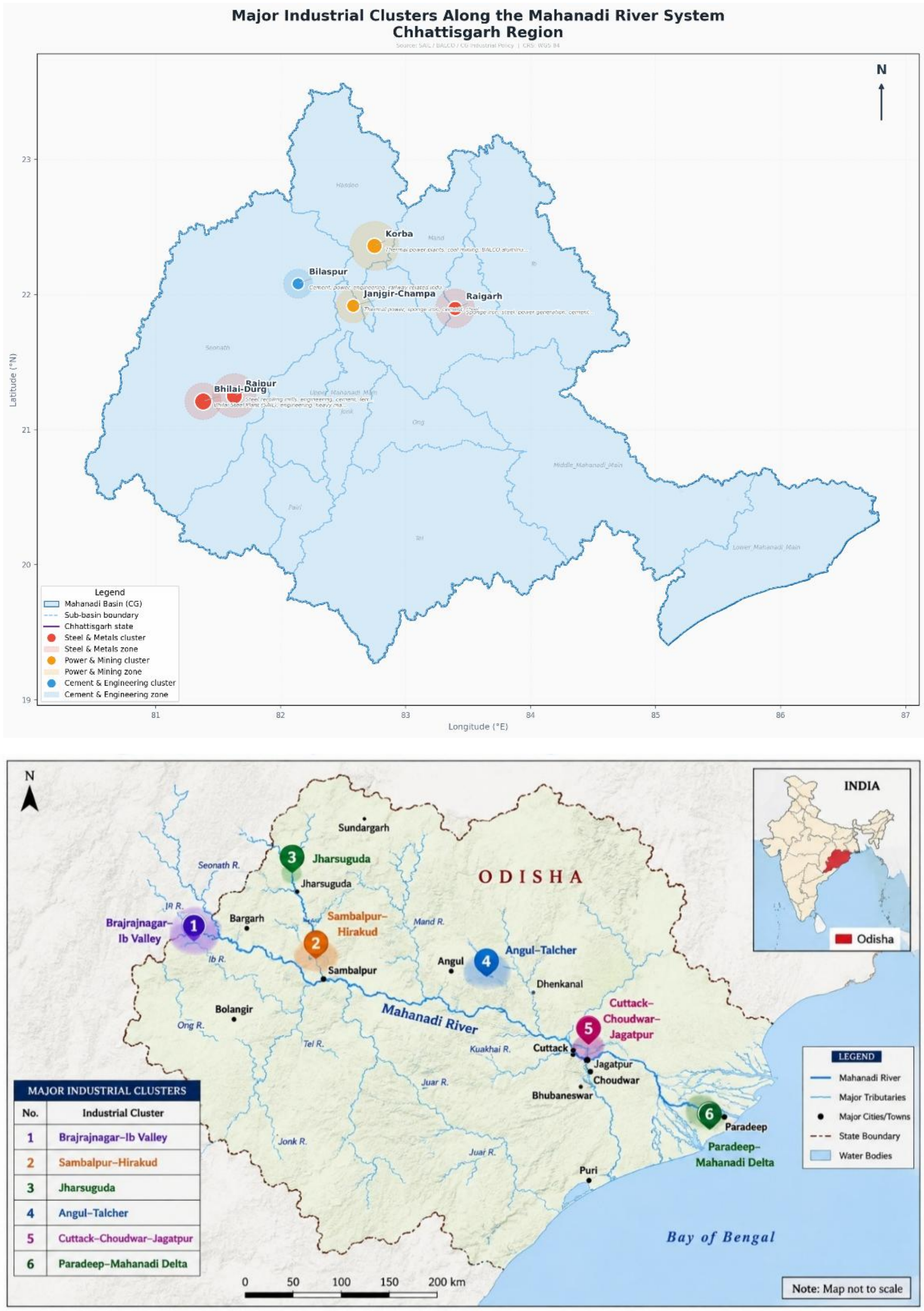
quality.

2.1 Key Industrial Hotspots and Clusters

2.1.1 Odisha

The major industrial clusters considered for the present assessment are spatially distributed along the Mahanadi River system and its associated industrial corridors, as shown in Figure 1. Based on the industrial characteristics of the Mahanadi basin and the preliminary assessment undertaken for this management plan, six major industrial clusters are considered for detailed assessment:

1. Brajrajnagar–Ib Valley
2. Sambalpur–Hirakud
3. Jharsuguda
4. Angul–Talcher
5. Cuttack–Choudwar–Jagatpur
6. Paradeep–Mahanadi Delta



(Source: Department of Water Resources, Government of Odisha; GIS Cell, Chief Engineer, HH, GIS & CEM (2022), and relevant industrial-location data)

Figure 2. Location of Major Industrial Clusters along the Mahanadi River System, Odisha

These clusters are defined as preliminary management clusters for the present assessment rather than as an official CPCB/OSPCB classification. The selection provides a practical basis for assessing industrial wastewater generation, pollutant characteristics, treatment infrastructure, water-reuse potential and receiving-water sensitivity. The final delineation of individual clusters should be established using verified industrial-unit locations, industrial production data, wastewater generation, pollutant loads, drainage connectivity and current regulatory records.

The preliminary industrial-cluster characterization was developed using a screening-based assessment of dominant industrial activities, expected wastewater characteristics and receiving-water context. The preliminary management priority was assigned qualitatively by considering wastewater pollutant potential, water-use intensity, the sensitivity of the receiving-water environment and the concentration and scale of industrial activities. The classifications of "High" and "Very High" represent preliminary management priorities and are not quantitative pollution-risk scores. These priorities should be refined using verified industry-wise wastewater generation, pollutant loads, treatment capacity, compliance records and receiving-water quality data.

TABLE 1 Preliminary Industrial Cluster Characterization and Management Priority

Cluster	Major industries	Major wastewater concerns	Receiving water	Preliminary Management Priority
Brajrajnagar–Ib	Thermal power, paper	BOD, COD, TSS, thermal/chemical loads	Ib/Mahanadi system	High
Sambalpur–Hirakud	Power, steel, urban-industrial	Organic load, TDS, metals	Mahanadi	High
Jharsuguda	Aluminium, steel, power	TDS, metals, cooling/industrial wastewater	Ib/Mahanadi system	Very High
Angul–Talcher	Power, mining, aluminium	TDS, ash-related wastewater, metals	Tributaries/Mahanadi	Very High
Cuttack–Choudwar–Jagatpur	Paper, chemical, MSME	BOD/COD, TSS, toxicants	Mahanadi/Kathajodi system	High
Paradeep	Fertilizer, petrochemical, port	Nutrients, salinity, chemicals	Estuary/coastal zone	Very High

Source: *Compiled from CPCB/OSPCB industrial-cluster assessments, Odisha environmental planning documents and published studies on industrial impacts in the Mahanadi system; management priority is a preliminary qualitative classification based on documented pollution status, industrial activity, wastewater characteristics and receiving-water sensitivity.*

2.1.2 Chhattisgarh

Chhattisgarh constitutes an important upstream and central component of the Mahanadi River Basin and is characterized by a strong resource-based industrial economy. The State possesses substantial deposits of coal, iron ore, limestone, bauxite and other mineral resources, which have supported the development of major industrial sectors such as iron and steel, sponge iron, cement, aluminium, thermal power, engineering, metal processing and mineral-based industries. In addition to these traditional core sectors, industrial development has progressively expanded into food processing, electronics, information technology, defence, railways, renewable energy, plastics and other manufacturing activities. The industrial profile of the State therefore represents a combination of large-scale resource-intensive industries and a broad network of micro, small and medium industrial units.

The industrial development of Chhattisgarh is closely associated with the availability of mineral resources, relatively large industrial land parcels, electricity-generation capacity and access to surface-water resources. Mahanadi, Hasdeo, Kelo and Shivnath (Seonath), are important components of the State's water-resource system and have historically supported domestic, agricultural and industrial water requirements. The concentration of water-intensive and potentially pollution-intensive industries within these catchments makes industrial water use and wastewater management an important component of basin-level environmental planning.

The State's industrial infrastructure has developed through both the Industrial Directorate and the Chhattisgarh State Industrial Development Corporation (CSIDC). The industrial-profile assessment identifies **26 established industrial areas under the Industrial Directorate** across districts including Rajnandgaon, Durg, Balod, Raigarh, Korba, Janjgir-Champa, Surguja, Koriya, Jagdalpur, Jashpur, Surajpur, Kondagaon and Narayanpur. In addition, **15 industrial areas under CSIDC** were identified across Raipur, Durg, Bilaspur, Mahasamund, Kabirdham, Surguja, Janjgir-Champa and Dantewada.

The industrial landscape is further supported by specialized industrial parks such as **Metal Park at Rawabhata, Engineering Park at Bhilai and the Food Park at Banjari–Bagod in Dhamtari**, along with other specialized industrial development initiatives. The industrial zones at Dogori in Bilaspur, Tilda in Raipur and Lara in Raigarh, represent the broader spatial distribution of industrial activity beyond the major established industrial estates.

2.1.2.1 Industrial concentration within major CSIDC estates

The CSIDC industrial-sector inventory demonstrates that industrial activity is particularly concentrated in a limited number of large industrial estates. Among the identified industrial sectors, Siltara, Urla, Sirgitti and Borai constitute major established industrial concentrations in terms of allocated industrial land and number of estimated industries.

TABLE 2 Established Industrial Sectors under CSIDC

S. No.	Industrial Sector	District/Location	Allocated Land (ha)	Estimated Industries	Reported Investment (₹ crore)	Employment
1	Siltara	Raipur	872.00	138	2,144.80	5,811
2	Borai	Durg	192.00	119	2,118.10	3,354
3	Urla	Raipur	270.00	331	563.63	13,678
4	Sirgitti	Bilaspur	235.76	317	513.18	5,059
5	Rani Durgavati Industrial Sector–Anjani	Pendra Road	10.89	19	10.76	359
6	Birkoni	Mahasamund	49.00	52	36.00	385
7	Harinchhapara	Kabirdham	11.40	7	2.00	150
8	Nayanpur–Girvarganj	Surguja	24.06	46	3.35	815
9	Silpahari	Bilaspur	157.56	10	200.18	840
10	Tifra	Bilaspur	39.48	120	13.77	875
11	Ravanbhata	Raipur	37.18	71	34.40	688
12	Bhanpuri	Raipur	103.48	177	202.23	1,698
13	Amashivani	Raipur	10.04	27	21.10	225
14	Kapan	Janjgir-Champa	55.98	—	—	—
15	Teknar	Dantewada	15.32	1	0.22	4
16	Engineering Park	Bhilai	55.98	—	—	—

Source: *CSIDC industrial-sector inventory reproduced in Mahanadi Industrial Profile Report.*

The Siltara Industrial Sector in Raipur occupies approximately 872 ha and has an estimated 138 industries, with reported investment of approximately ₹2,144.80 crore and employment of about 5,811 persons. The Urla Industrial Sector in Raipur, although smaller in geographical extent at approximately 270 ha, has an estimated 331 industries, representing one of the highest concentrations of individual industrial units in the CSIDC inventory. The Sirgitti Industrial Sector in Bilaspur extends over approximately 235.76 ha and has an estimated 317 industries, while Borai Industrial Sector in Durg covers approximately 192 ha with an estimated 119 industries.

These four industrial sectors together account for approximately 1,570 ha of allocated industrial land and 905 estimated industrial units in the CSIDC inventory. This concentration is particularly relevant for industrial wastewater management because a relatively large number of industrial units are located within defined geographical clusters, creating the possibility of common drainage pathways, cumulative pollutant loading, shared receiving water bodies and potential opportunities for collective wastewater-management infrastructure.

The CSIDC inventory also identifies a number of smaller industrial sectors, including Rani Durgavati Industrial Sector–Anjani at Pendra Road, Birkoni in Mahasamund, Harinchhapara in Kabirdham, Nayanpur–Girvarganj in Surguja, Silpahari and Tifra in Bilaspur, Ravanbhata and Bhanpuri in Raipur, Amashivani, Kapan in Janjgir-Champa and Teknar in Dantewada.

2.1.2.2 Specialized Industrial Parks and Industrial Clusters

Alongside conventional industrial estates, Chhattisgarh has developed or proposed sector-specific industrial parks intended to promote specialization and downstream industrial development. The industrial-profile assessment identifies Metal Park at Rawabhata, Engineering Park at Bhilai and Food Park at Banjari–Bagod, Dhamtari. The reported industrial infrastructure also includes the Herbal Medicinal and Food Park at Banjari–Bagod, Metal Park at Rawabhata, Gems & Jewellery SEZ at New Raipur, Engineering Park at Bhilai and Apparel Park at Bhanpuri, Raipur.

The State's industrial-cluster structure also includes several district-level clusters. These include re-rolling mills in Raipur; rice-mill clusters in Raipur, Rajim, Tilda-Neora and Dhamtari; poha mills in Balodabazar and Rajnandgaon; engineering clusters in Rajnandgaon; stone cutting and polishing in Mahasamund; and mineral/metal-related clusters in Raigarh.

This indicates that industrial wastewater management in Chhattisgarh cannot be limited to large industrial estates alone. Small and medium industrial clusters can also contribute cumulatively to wastewater loads, particularly where multiple units discharge into common drains or watercourses. Consequently, the basin-level assessment should consider both large point sources and geographically concentrated groups of smaller industries.

TABLE 3 Major Industrial Areas and Clusters Relevant to Industrial Wastewater Management

Industrial Area/Cluster	Location	Industrial Character	Relevance for Mahanadi Basin Assessment
IGC Siltara	Raipur	Major established industrial sector	High-priority cluster for industry-wise wastewater and pollutant-load assessment
IGC Urla	Raipur	Large number of industrial units	High priority for cumulative wastewater-load assessment
IGC Bhanpuri–Rawabhata	Raipur	Industrial and specialized manufacturing activities	Assessment of common drainage, ETP performance and receiving-water connectivity
IGC Borai	Durg	Major established industrial sector	Priority assessment of industrial effluent and receiving-water impacts
IGC Sirgitti	Bilaspur	Large established industrial sector	Assessment of wastewater generation, ETP coverage and discharge pathways
Tifra Industrial Area	Bilaspur	Established industrial sector	Assessment of small/medium industrial wastewater generation
Anjani Industrial Area	Pendra Road	Smaller industrial sector	Screening-level assessment and basin connectivity
IIDC Harinchhapara	Kabirdham	Industrial development centre	Assessment based on industry type and wastewater characteristics
IIDC Birkoni	Mahasamund	Industrial development centre	Important for assessment of industrial activity within the Mahanadi catchment
IIDC Nayanpur–Girvarganj	Surguja	Industrial development centre	Screening based on catchment connectivity and receiving waterbody
Silpahari	Bilaspur	Established industrial sector	Industry-wise wastewater inventory
Ravanbhata	Raipur	Industrial sector / metal-related development	Priority assessment due to industrial concentration
Kapan	Janjgir-Champa	Industrial development centre	Screening of industrial wastewater potential
Engineering Park	Bhilai	Engineering-sector industrial park	Sector-specific wastewater assessment
Metal Park	Rawabhata	Metal-sector industrial park	High priority for metal-related pollutants and ETP performance
Food Park	Banjari–Bagod, Dhamtari	Food/agro-processing	Assessment of organic wastewater characteristics

2.2 Industrial Clusters and CETP Requirements

The wastewater-management requirements of industrial clusters depend on the number and type of industries, wastewater generation, pollutant loading, existing treatment infrastructure and compatibility of industrial effluents. Large industries generally have greater technical and financial capacity to operate individual Effluent Treatment Plants (ETPs), whereas small and medium-scale industries may face constraints related to land availability, capital investment, technical manpower and operation and maintenance. In such situations, a Common Effluent Treatment Plant (CETP) can provide a shared treatment option for compatible industrial wastewater streams (Pathe et al., 2004; Ghumra et al., 2021).

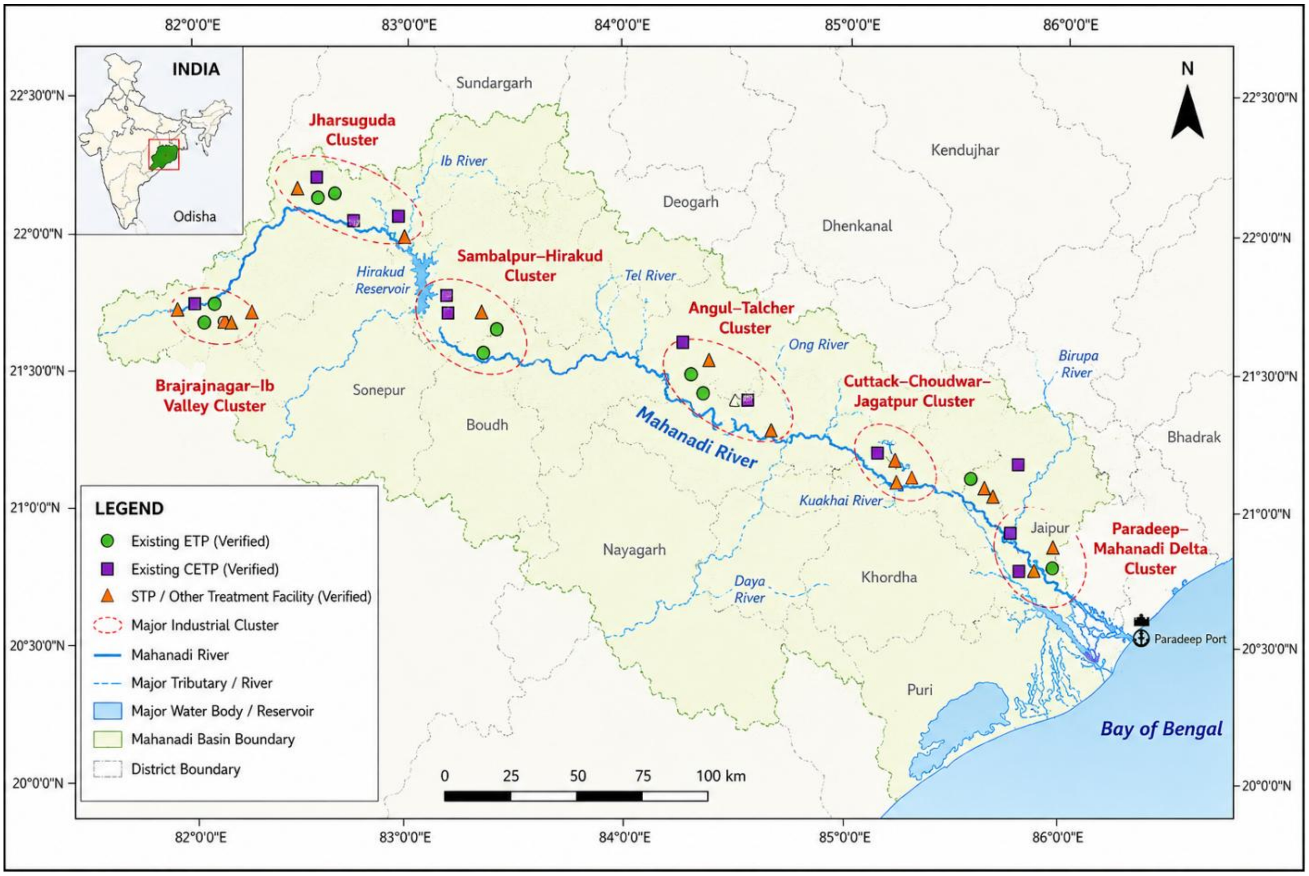
Research has demonstrated that CETPs can provide collective treatment for clusters of small and medium-scale industries; however, their effectiveness depends on appropriate influent characteristics, hydraulic and organic loading, treatment-process performance and operational reliability. Therefore, CETP assessment should consider both pollutant-removal efficiency and operational reliability rather than relying only on design capacity or average treated-effluent concentrations. Padalkar and Kumar (2018) evaluated CETP performance using parameters including BOD, COD, TSS and oil and grease and highlighted the importance of reliability and actual treatment performance in CETP evaluation.

2.2.1 Existing Wastewater Treatment Infrastructure and ETP Requirements in Odisha

The existing wastewater-treatment infrastructure should be assessed cluster by cluster rather than only at the state or basin level. The assessment should distinguish between individual ETPs, CETPs, STPs and other treatment systems because these facilities serve different wastewater sources.
The following information should be compiled for each treatment facility:

- Design treatment capacity
- Actual wastewater received
- Average and peak hydraulic loading
- Treatment technology
- Influent and treated-effluent quality
- Removal efficiency
- Compliance history

- Operating hours and downtime
- Sludge generation
- Treated-water reuse
- Final discharge location



Source: *Based on available regulatory and industrial-facility information; treatment-facility locations require verification from current OSPCB and industry records.*

Figure 3. Spatial Distribution of Major Industrial Clusters and Identified Wastewater-Treatment Infrastructure along the Mahanadi Industrial Corridor.

The current preliminary inventory reported in the working document should be treated as a baseline for verification. The final report should use current records from the relevant regulatory and industrial sources before presenting these values as confirmed infrastructure capacity.

The spatial distribution of the identified wastewater-treatment infrastructure and major industrial clusters along the Mahanadi industrial corridor is presented in Figure 2. The map provides a preliminary spatial representation of identified ETPs, CETPs and other treatment facilities and should be updated following verification of facility locations and current regulatory records.

2.2.2 Industrial Wastewater Generation and Treatment Status in Chhattisgarh

Chhattisgarh has a significant and geographically distributed industrial base, with industrial activities ranging from mineral-based and metallurgical industries to thermal power, cement, food processing, engineering and other manufacturing sectors. Given the concentration of industries within defined industrial estates as well as dispersed industrial clusters, industrial wastewater represents an important component of the overall pollution load within the Chhattisgarh portion of the Mahanadi River Basin.

The industrial wastewater baseline reported by the Chhattisgarh Environment Conservation Board (CECB) provides an important starting point for assessing the scale of the issue. As reported in the CECB's December 2022 Monthly Progress Report, the State had 6,475 industries, of which 1,040 were classified as water-polluting industries. Among these, 178 water-polluting industries were located within identified polluted river stretches. The quantity of industrial effluent generated by industries located within these polluted river stretches was reported as approximately 132.42 MLD.

The same assessment reported 946 industrial units having Effluent Treatment Plants (ETPs). It further reported that there was no Common Effluent Treatment Plant (CETP) in Chhattisgarh, and that water-polluting industries were dependent on individual ETP systems. The CECB report stated that the operational ETPs were complying with the prescribed effluent standards and that no CETP was under construction at the time of the assessment.

This indicates that the industrial wastewater management model in Chhattisgarh has historically been based predominantly on source-level treatment through individual ETPs, rather than collective treatment through CETPs. While individual ETPs provide an important mechanism for controlling pollution at source, the presence of a large number of industries within concentrated industrial estates raises the need to assess their actual treatment performance, cumulative pollutant loads, common drainage pathways, treated-water reuse and receiving-water impacts.

It is therefore important to distinguish between installed treatment infrastructure and effective wastewater treatment. The presence of an ETP does not necessarily establish that the complete wastewater generated by an industry is adequately treated. An effective assessment should consider the actual hydraulic loading of the ETP, pollutant loading, treatment efficiency, operational reliability, compliance history, sludge management, treated-water reuse and final discharge/reuse pathway. The existing management-plan framework similarly recommends that ETPs be assessed using actual operating performance rather than design capacity alone.

2.2.3 State-Level Industrial Wastewater Baseline

The available CECB baseline provides the following overview of industrial wastewater management in Chhattisgarh. The reported figures indicate that approximately **16% of all industries** in the State were classified as water-polluting industries. Further, approximately **17% of the identified water-polluting industries** were located within polluted river stretches. The reported 132.42 MLD of effluent generation from these industries represents a substantial concentrated wastewater load requiring systematic monitoring and management.

(Source: Chhattisgarh Environment Conservation Board, Monthly Progress Report, December 2022).

FIGURE 4 Industrial Wastewater Management Baseline in Chhattisgarh

However, the reported 132.42 MLD should not be interpreted directly as the industrial wastewater treatment gap. The quantity represents reported effluent generation from industries located in polluted river stretches; it does not provide sufficient information on the actual treatment capacity, hydraulic utilization, pollutant-removal efficiency or treated-effluent reuse of individual ETPs.

The treatment gap should instead be determined using the difference between wastewater requiring treatment and effective treatment capacity, with effective capacity reflecting actual operating conditions and verified treatment performance. The assessment should therefore compare wastewater generation with actual treatment flow, peak hydraulic loading, pollutant loading, treatment efficiency, reuse and final discharge.

2.3 ETP Requirements and Performance Assessment

Effluent Treatment Plants (ETPs) should be provided and adequately operated by industrial units generating wastewater where treatment is required to meet applicable discharge, reuse or regulatory requirements. The treatment system should be designed according to the quantity and characteristics of wastewater generated by the specific industrial process.

The treatment requirement should not be determined solely by industrial category. It should also consider wastewater flow, pollutant concentration, pollutant load, receiving-water sensitivity and the intended reuse or discharge pathway.

Industries generating high-strength wastewater or streams containing toxic constituents, heavy metals, oil and grease or other sector-specific contaminants should provide appropriate source-level pretreatment before discharge to a common treatment system, where applicable.

Existing ETPs should be evaluated using both design and actual operating performance. The assessment should consider design capacity, actual hydraulic and pollutant loading, treatment efficiency, operational reliability, compliance with applicable discharge standards, sludge management, energy requirements, treated-water reuse and provision for emergency storage and bypass prevention. ETP/CETP performance should be evaluated using actual removal efficiency and operational reliability rather than design capacity alone (Padalkar & Kumar, 2018).

At the present assessment stage, verified industry-wise ETP performance data for all identified Mahanadi industrial clusters are not available. Therefore, the proposed framework identifies the parameters and data requirements for subsequent field-level ETP performance assessment using industry records, regulatory information, monitoring data and field verification.

The ETP should be evaluated based on:

- Design capacity
- Actual loading
- Treatment efficiency
- Reliability
- Compliance
- Sludge management
- Energy consumption
- Treated-water reuse
- Emergency storage and bypass prevention

2.4 Regulatory Framework and Compliance

Industrial wastewater management across the Mahanadi River Basin in Chhattisgarh and Odisha shall comply with the applicable environmental regulatory framework governing prevention and control of water pollution, consent conditions, effluent discharge standards, hazardous-waste management and online monitoring. The regulatory assessment should consider the requirements applicable to individual industrial units as well as cluster-level treatment facilities, including permitted wastewater generation and discharge quantities, authorized discharge locations, applicable effluent standards, treatment and monitoring requirements, compliance history, identified deficiencies, corrective actions and enforcement measures, wherever applicable.

The assessment should also include the regulatory requirements associated with hazardous-waste generation and management, including authorization, storage, transportation, treatment, recovery and final disposal of hazardous wastes and treatment residues. For industries equipped with online monitoring systems, the availability, operational status and reliability of OCEMS data should also be considered as part of the compliance assessment.

For the Chhattisgarh portion of the basin, the assessment should be coordinated with the Chhattisgarh Environment Conservation Board (CECB), while the Odisha component should be assessed in coordination with the Odisha State Pollution Control Board (OSPCB), along with CPCB and other relevant authorities. The regulatory assessment should also account for industries located within or influencing identified polluted river stretches, where receiving-water protection requires enhanced monitoring and compliance oversight.

For effective implementation of the management plan, regulatory compliance should be assessed through a unit-wise compliance matrix covering the applicable regulatory requirements, consent conditions, wastewater generation and discharge, ETP performance, monitoring status, compliance gaps, hazardous-waste management and required corrective actions. This approach will provide a systematic basis for identifying priority non-compliance, strengthening enforcement and tracking improvement over time, rather than relying on generalized statements of regulatory compliance.

2.5 Industrial Wastewater Treatment Gap and CETP Requirements

The treatment gap represents the difference between wastewater requiring treatment and the effective treatment capacity available.

The assessment should consider not only installed capacity but also actual operating capacity. An ETP with a large design capacity but low utilization, frequent downtime or poor removal efficiency should not automatically be considered an adequate treatment facility.

The treatment gap should therefore be calculated using:

Treatment Gap = Wastewater Requiring Treatment – Effective Treatment Capacity (2.1)

where effective treatment capacity should account for actual operation and verified treatment performance.

For each industrial cluster, the following should be compared:

- Total wastewater generation
- Existing treatment capacity
- Actual treatment flow
- Peak flow
- Pollutant load
- Treatment efficiency
- Treated-water reuse
- Final discharge
- Additional treatment requirement

This analysis will allow the management plan to identify whether the appropriate intervention is ETP augmentation, ETP modernization, CETP development, treated-water reuse or advanced treatment/ZLD.

A CETP should be considered where a sufficient concentration of compatible industries exists and where collective treatment provides technical, economic or environmental advantages over individual treatment systems.

The CETP assessment should consider five major components:

a) **Hydraulic feasibility:**
The combined wastewater flow, average flow, peak flow and seasonal variation should be established to determine the required CETP capacity.

b) **Pollutant-load feasibility:**
BOD, COD, TSS, TDS, oil and grease, nutrients, heavy metals and sector-specific contaminants should be quantified.

c) **Effluent compatibility:**
Industries producing incompatible or highly toxic wastewater should not discharge directly into a common system without appropriate pretreatment.

d) **Conveyance feasibility:**
The location of industries, drainage pathways, pipeline length, pumping requirements and land availability should be assessed.

e) **Operational and financial feasibility:**
The CETP requires a sustainable O&M mechanism, skilled manpower, monitoring, user charges and clearly defined responsibility.

The CETP should therefore be considered a **cluster-management infrastructure**, not simply a treatment plant.

2.6 CETP Feasibility Assessment

The feasibility of CETPs should be evaluated using a multi-criteria approach. The following indicators should be considered:

- Industrial density
- Number of participating industries
- Wastewater generation
- Pollutant loading
- Compatibility of wastewater
- Existing individual ETP performance

- Land availability
- Conveyance distance
- Receiving-water sensitivity
- Treated-water reuse potential
- Capital cost
- Operation and maintenance cost
- Institutional arrangements
- Expected compliance improvement

Padalkar and Kumar (2018) demonstrate that CETP evaluation should include both pollutant-removal efficiency and reliability. Their study considered BOD, COD, TSS and oil and grease and showed that treatment performance can fluctuate when hydraulic and organic loading are not appropriately controlled. This supports the use of reliability and actual operating performance, rather than design capacity alone, in evaluating CETP requirements for the Mahanadi industrial clusters.

2.7 Strategy for Collective Waste Management

The collective wastewater-management strategy aims to establish an integrated system in which industrial wastewater is controlled at source, transported through an appropriate collection system, treated through individual or common facilities and reused wherever technically feasible.

The strategy should follow the hierarchy:

Source reduction → segregation → pretreatment → collection → common treatment → advanced treatment where required → reuse → controlled residual management.

The objective is to minimize untreated discharge into the Mahanadi and its tributaries while reducing freshwater abstraction and improving industrial water-use efficiency.

The monitoring framework should therefore consist of:

Online monitoring → centralized database → data validation → threshold detection → alert → inspection/corrective action → verification.

Mahanadi research demonstrates the value of combining conventional monitoring with statistical analysis. Pany et al. (2023) used PCA, FA and Cluster Analysis to identify influential water-quality parameters and applied ANN models for prediction. Their results demonstrate the potential of data-driven monitoring to provide early information for preventive management.

3. ZLD IMPLEMENTATION

Zero Liquid Discharge (ZLD) is an advanced industrial wastewater-management approach in which treated wastewater is recovered for reuse and the remaining concentrated constituents are converted into a solid or semi-solid residual for appropriate recovery, treatment or disposal. ZLD therefore aims to minimize or eliminate the discharge of liquid effluent from an industrial facility while promoting water recovery and internal reuse.

For the Mahanadi River Basin, ZLD should be considered as a sector-specific and site-specific management option, particularly for water-intensive industries and industrial streams where conventional treatment and reuse are insufficient to meet applicable discharge requirements or where freshwater conservation objectives justify advanced treatment. ZLD should not, however, be treated as a universal requirement for every industrial unit. Government guidance emphasizes treatment to prescribed standards, wastewater reduction, reuse/recycling and maintaining ZLD wherever technically feasible, while CPCB has also issued sector-specific directions for identified highly polluting sectors.

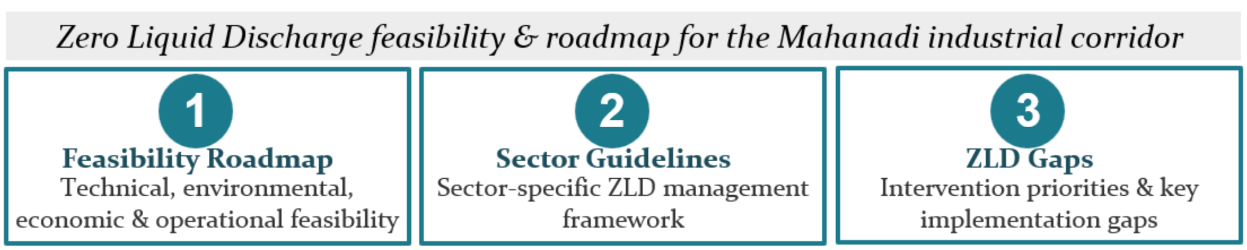


Figure 5. Liquid Discharge feasibility and roadmap

A ZLD system generally consists of a combination of source segregation, pretreatment, biological and/or physicochemical treatment, membrane processes such as ultrafiltration or reverse osmosis, concentration of the reject stream through evaporation and, where required, crystallization. The recovered water can be returned to suitable industrial processes, while salts and other concentrated residuals require appropriate recovery or authorized management (CPCB, 2015; CPCB, 2021).

3.1 ZLD Feasibility and Implementation Roadmap

3.3.1 Technical Feasibility

Zero Liquid Discharge (ZLD) is technically feasible for selected water-intensive and high-pollution industrial sectors along the Mahanadi industrial corridor, particularly where conventional treatment and water-reuse systems are insufficient to meet discharge requirements. The implementation should integrate wastewater segregation, equalization, physicochemical and biological treatment, membrane-based processes, evaporation and crystallization, as appropriate to the wastewater characteristics. ZLD systems should be designed based on sector-specific wastewater quality, flow, Total Dissolved Solids (TDS), and contaminant loads.

3.3.2 Environmental Feasibility

ZLD can significantly reduce the discharge of treated industrial effluent into the Mahanadi and promote the recovery and reuse of treated water. Its environmental feasibility depends on minimizing secondary waste generation, ensuring safe management of concentrated brine and treatment residues, and preventing contamination of soil and groundwater. Priority should therefore be given to industries located near sensitive river stretches and those generating high pollutant loads.

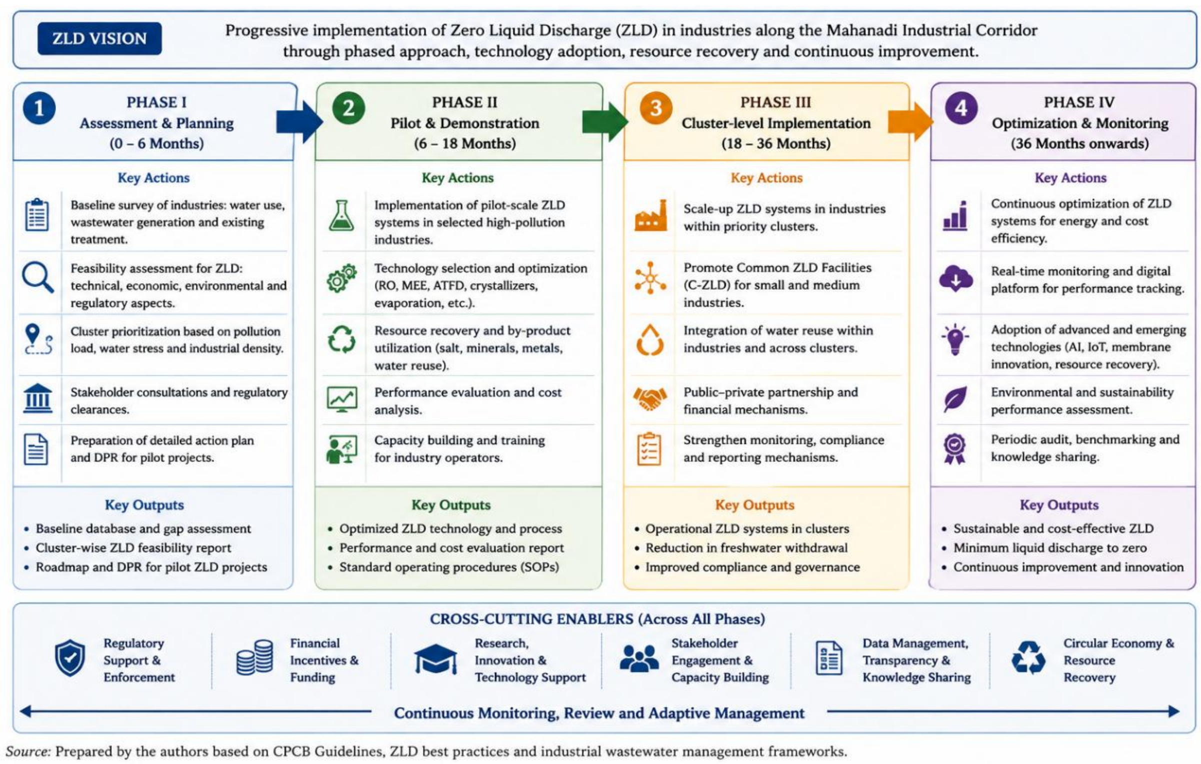
3.3.3 Economic Feasibility

ZLD involves relatively high capital and operating costs because of advanced treatment, membrane systems, evaporation and residue-management requirements. Therefore, implementation should prioritize industries and industrial clusters where water consumption, pollution potential and water-reuse benefits justify the investment. Shared infrastructure, including CETPs and common recovery facilities, may improve economic feasibility for clusters containing small and medium-scale industries.

3.3.4 Operational Feasibility

Successful ZLD implementation requires reliable operation and maintenance of treatment systems, skilled technical personnel, regular monitoring and proper management of concentrated residues. Industries should establish standard operating procedures, preventive maintenance schedules and continuous monitoring systems. Periodic performance evaluation should be undertaken to ensure that recovered water quality and ZLD performance remain consistent with applicable regulatory requirements.

Based on the technical, environmental, economic and operational considerations discussed above, a phased, sector- and cluster-specific ZLD implementation approach is proposed for the Mahanadi industrial corridor. The approach considers wastewater characteristics, water consumption, pollution potential, treatment feasibility and opportunities for treated-water reuse. The implementation sequence includes wastewater characterization and segregation, treatment and water recovery, concentrate management, reuse of recovered water and periodic performance evaluation (CPCB, 2015; CPCB, 2021; MoEFCC, 2016; Ministry of Jal Shakti, 2023), as presented in Figure 4.



Source: *Author's synthesis based on CPCB (2015), CPCB (2021), MoEFCC (2016), and Ministry of Jal Shakti (2023).*

Figure 6 ZLD Implementation and Feasibility Roadmap for the Mahanadi Industrial Corridor

3.2 Sector-Specific ZLD Guidelines

Zero Liquid Discharge (ZLD) requirements should be applied according to the wastewater characteristics, water consumption, pollution potential and treatment feasibility of individual industrial sectors. The objective is to maximize wastewater recovery and reuse while minimizing liquid effluent discharge outside the industrial premises. ZLD should be prioritized for highly water-intensive and pollution-intensive industries where technically and economically feasible.

The sector-specific ZLD management framework for major industrial sectors is presented in Table 4.

TABLE 4 Sector-Specific ZLD Management Framework for Industrial Wastewater

Sl. No.	Industry Sector	Typical Wastewater Characteristics	Recommended ZLD/Advanced Treatment Approach
1	Thermal Power Plants	Cooling-tower blowdown, ash-related wastewater, high TDS	Water conservation, stream segregation, treatment and reuse; advanced concentration/ZLD for suitable high-TDS streams
2	Textile and Dyeing	High colour, COD, TDS and process chemicals	Segregation, biological/physicochemical treatment, RO and concentrate management where required
3	Tanneries	Chromium, sulphides, high TDS and organic matter	Chromium recovery, physicochemical treatment, RO and concentrate management
4	Pharmaceutical	High COD, solvents, complex organic compounds	Source segregation, solvent recovery, biological/advanced treatment and RO/evaporation where required
5	Chemical Industries	High salinity, toxic and chemically complex wastewater	Source reduction, stream segregation, physicochemical treatment and recovery/concentration
6	Pulp and Paper	High organic load, colour, TSS and process chemicals	Primary/biological treatment, water reuse and advanced treatment where required
7	Food and Beverage	High BOD/COD and suspended solids	Biological treatment, tertiary treatment and treated-water reuse; ZLD where technically justified
8	Electroplating	Heavy metals, acids/alkalis and dissolved salts	Metal recovery, precipitation, ion exchange/membrane treatment and concentrate management
9	Fertilizer	Ammonia, urea, nutrients and dissolved salts	Nutrient recovery, condensate recovery, process-water reuse and advanced treatment where required
10	Mining and Mineral Processing	Suspended solids, metals, variable TDS	Sedimentation/thickening, filtration, water recovery and process-water reuse

Source: *Adapted from CPCB (2015, 2021), IFC (2007), Metcalf & Eddy/AECOM (2014) and Ministry of Jal Shakti (2023).*

For the Mahanadi industrial corridor, ZLD implementation should be risk- and feasibility-based rather than uniformly imposed on every industry. Priority should be given to industries with high water consumption, high pollutant loads, high-TDS effluent and significant risk to sensitive receiving waters. Industries that cannot immediately achieve full ZLD should first implement source reduction, wastewater segregation, treatment and maximum feasible reuse, followed by progressive improvement toward higher water recovery.

3.3 ZLD Gaps

The implementation of Zero Liquid Discharge (ZLD) along the Mahanadi industrial corridor faces technical, economic, infrastructural and regulatory challenges. ZLD adoption is not uniform across industrial clusters, and several industries continue to depend on conventional treatment followed by permitted discharge. The preliminary assessment of Zero Liquid Discharge (ZLD) requirements across the major industrial clusters of the Mahanadi River Basin is presented in Table 5. The assessment covers major industrial clusters in both Chhattisgarh and Odisha and considers the nature of industrial activities, wastewater characteristics, water-use intensity, existing treatment practices, opportunities for water recovery and the potential for concentrate generation.

ZLD requirements vary considerably among industrial sectors and clusters. High water-consuming and mineral- or metal-based industries generally have greater potential for generation of high-TDS and complex wastewater streams, while thermal power and mining activities are associated with cooling-water blowdown, ash-related wastewater and mine-water management. Mixed industrial clusters containing small and medium industries may have heterogeneous wastewater characteristics and variable treatment performance, making common advanced treatment and water-recovery systems more challenging.

For Chhattisgarh, the assessment is particularly relevant to the major industrial centres of **Korba, Raigarh, Raipur–Siltara–Urla and Durg–Bhilai**, where mineral-based industries, steel, thermal power, metal processing and engineering industries are concentrated. The industrial profile indicates substantial industrial water demand in Korba, Raigarh, Durg and Raipur. The CECB baseline further reports 1,040 water-polluting industries in the State, including 178 industries located within identified polluted river stretches.

Table 5 Preliminary Cluster-Wise ZLD Gaps along the Mahanadi Industrial Corridor

Sl. No.	Industrial Cluster	State	Major Industries	Key ZLD Gaps
1	**Jharsuguda–Sambalpur–Hirakud**	Odisha	Aluminium, power, steel	High-TDS streams, cooling-water blowdown, ash-related wastewater and variable adoption of advanced treatment and water-recovery systems

2	**Angul–Talcher**	Odisha	Thermal power, coal mining, aluminium	Mine-water reuse, ash-related wastewater management, cooling-water blowdown and incomplete industrial-water recycling
3	**Cuttack–Choudwar–Jagatpur**	Odisha	Engineering, food processing, chemicals and MSMEs	Variable ETP performance, heterogeneous wastewater characteristics and limited common treatment and water-recovery options for compatible small-unit streams
4	**Paradeep–Mahanadi Delta**	Odisha	Fertilizer, petrochemical, refinery and port-related industries	Salinity, complex industrial wastewater, stormwater interaction, high-TDS streams and concentrate management
5	**Korba Industrial Cluster**	Chhattisgarh	Thermal power, coal-based industries, aluminium and mineral-based industries	High industrial water consumption, cooling-water blowdown, ash-related wastewater, high-TDS streams and requirement for increased recycling and water recovery
6	**Raigarh Industrial Cluster**	Chhattisgarh	Steel, sponge iron, thermal power and mineral-based industries	High-TDS and metal-bearing wastewater, cooling-water blowdown, process-water recycling and management of concentrated reject streams
7	**Siltara–Urla Industrial Cluster**	Chhattisgarh	Steel, metal processing, engineering and manufacturing	Heterogeneous wastewater characteristics, variable ETP performance, high-strength streams and limited cluster-level treated-water recovery
8	**Durg–Bhilai Industrial Cluster**	Chhattisgarh	Steel, engineering, metal processing and associated industries	High-volume process and cooling wastewater, ETP optimization, water recycling and recovery of suitable industrial streams
9	**Sirgitti–Tifra Industrial Cluster**	Chhattisgarh	Manufacturing, engineering and small and medium industries	Variable wastewater characteristics, individual ETP limitations, process-water recycling and need for improved tertiary treatment and water recovery
10	**Bhanpuri–Rawabhata / Metal Park**	Chhattisgarh	Metal processing, engineering and manufacturing	Metal-bearing and high-TDS streams, ETP performance improvement, process-water recycling and advanced

				treatment requirements for selected streams

Note: The identified ZLD gaps represent a preliminary cluster-level assessment. Final determination of ZLD requirements should be based on industry-wise water balances, wastewater characteristics, existing treatment performance, reuse potential, concentrate generation and technical and economic feasibility.

In Chhattisgarh, the ZLD requirement is closely associated with the concentration of water-intensive and resource-based industries. The industrial water assessment identifies Korba, Raigarh, Durg and Raipur as important industrial water-demand centres. Korba is characterized by coal-based and thermal-power activities, while Raigarh has experienced substantial industrial development associated with thermal power and steel. The Durg–Bhilai industrial belt has historically been dominated by steel and heavy industries, while Raipur has developed as a diversified industrial and manufacturing centre.

The industrial wastewater treatment system in Chhattisgarh is predominantly based on individual ETPs. The CECB December 2022 baseline reported 946 industrial units with ETPs, while no CETP was reported at that time. Consequently, ZLD implementation in the State should focus initially on improving water-use efficiency, maximizing internal recycling, optimizing existing ETPs and introducing advanced treatment for specific high-TDS or difficult-to-treat wastewater streams.

For thermal-power and mineral-based clusters, particular attention is required for cooling-water blowdown, ash-related wastewater, high-TDS streams and process-water recycling. In steel and metal-processing clusters, treatment and recovery of metal-bearing wastewater and concentrated process streams should receive priority. In mixed industrial clusters such as Siltara–Urla, Bhanpuri–Rawabhata and Sirgitti–Tifra, wastewater characteristics may vary substantially between industries; therefore, source segregation and industry-specific pretreatment are important prerequisites for effective cluster-level water recovery.

3.3.1 ZLD Intervention Priorities

The ZLD strategy for the Mahanadi industrial corridor should follow a progressive treatment and recovery approach as shown in figure 5. ZLD should therefore be adopted where the characteristics of the industrial wastewater, water-reuse potential, receiving-water sensitivity and technical and economic considerations justify its implementation. The approach is consistent with the broader industrial wastewater management framework, which emphasizes source reduction, treatment optimization, recycling, reuse and advanced treatment prior to consideration of ZLD.

Overall, the cluster-wise assessment indicates that ZLD requirements within the Mahanadi basin are sector- and location-specific rather than uniform across all industries. The major requirement is to increase industrial water recovery, reduce freshwater demand, improve treatment performance and progressively manage high-TDS and concentrated wastewater streams. For Chhattisgarh, this approach is particularly relevant to the Korba, Raigarh, Raipur–Siltara–Urla and Durg–Bhilai industrial regions, while in Odisha priority remains with the major aluminium, thermal-power, steel, chemical, petrochemical and port-linked industrial clusters.

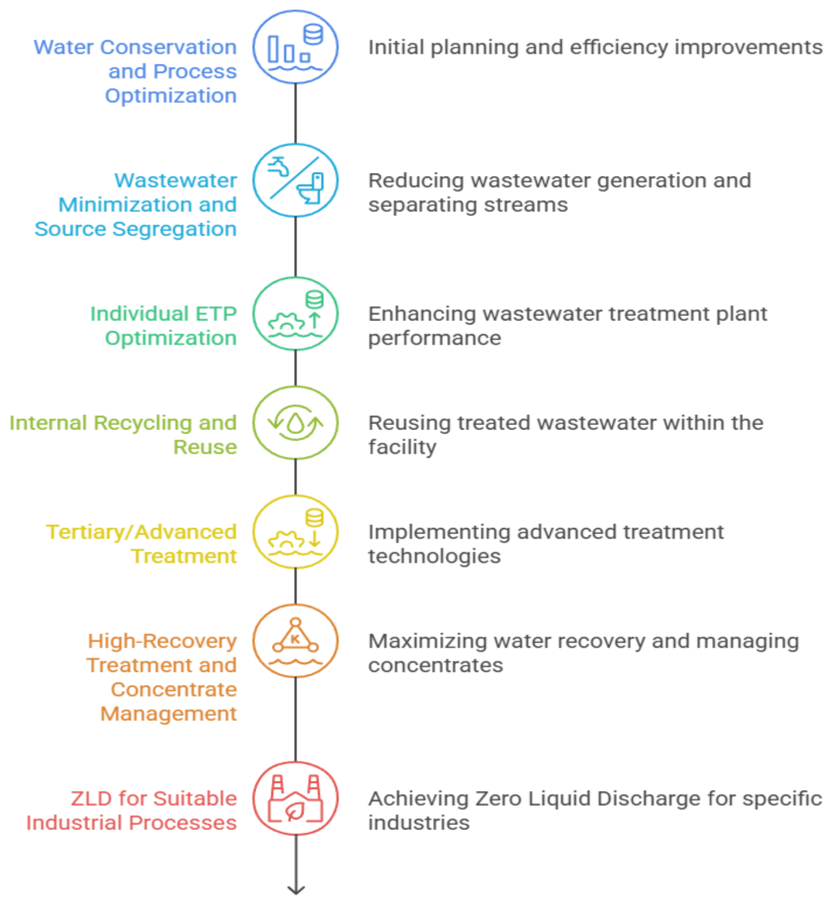


Figure 7 ZLD strategy for the Mahanadi industrial corridor

3.3.2 Key Implementation Gaps

The major implementation gaps are:

- Uneven ZLD adoption: ZLD is not required uniformly for all industries; therefore, conventional treated-effluent discharge continues where permitted under applicable standards.

- High capital and operating costs: RO, evaporators and crystallizers require significant investment and energy, creating challenges particularly for MSMEs.
- Limited common infrastructure: Industrial clusters with numerous smaller units require shared treatment and water-recovery facilities.
- High-TDS and concentrate management: Membrane fouling, scaling, reject brine and concentrated salt residues require specialized management.
- Legacy pollution: Existing ash ponds, contaminated drains and historical waste-storage areas may continue to affect nearby water bodies even after installation of new ZLD systems.
- Monitoring and enforcement gaps: Continuous monitoring, periodic inspection, data verification and proper operation and maintenance of treatment systems need strengthening.

4. HAZARDOUS WASTE

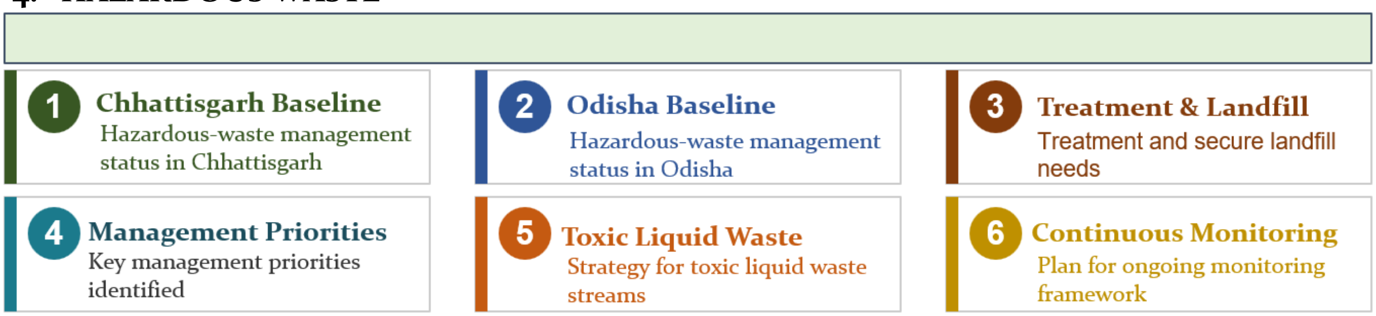


Figure 8. hazardous waste management, treatment and monitoring

4.1 Hazardous waste management in Chhattisgarh

Hazardous waste management is an important component of industrial environmental management in the Chhattisgarh portion of the Mahanadi River Basin because of the concentration of mineral-based, metallurgical, thermal power, cement, aluminium, fertilizer and other industrial activities. Hazardous waste generated from these sectors includes waste oil and oil sludge, cathode residues, tar residues, metal-bearing ash, slag and dross, sulphur-containing residues and other process-specific wastes. The Chhattisgarh Environment Conservation Board (CECB) identifies cement plants, iron and steel plants, fertilizer plants, aluminium plants, power plants, waste-processing units and mine workshops among the principal hazardous-waste-generating sectors in the State.

The CECB's December 2022 compliance assessment reported 413 hazardous-waste-generating industries in Chhattisgarh, with total hazardous-waste generation of approximately 172,437.78 tonnes per year. At the time of the reported assessment, the treatment capacity of TSDFs in the State was reported as nil, and the quantity of hazardous waste reaching and being treated at TSDFs was also reported as nil. The assessment further recorded that establishment of a Common Hazardous Waste Treatment, Storage and Disposal Facility (CHWTSDF) had been initiated by CSIDC under the guidance of the Department of Commerce and Industry, Government of Chhattisgarh.

TABLE 6 Hazardous Waste Management Baseline in Chhattisgarh

Parameter	**Reported Status**
Hazardous-waste-generating industries	**413**
Hazardous waste generation	**172,437.78 tonnes/year**
Reported TSDF treatment capacity	**Nil**
Average hazardous waste reaching TSDFs and treated	**Nil**
Common TSDF initiative	**Initiated through CSIDC**
Principal hazardous-waste-generating sectors	Cement, iron & steel, fertilizer, aluminium, power, waste processing and mine workshops
Baseline	CECB MPR, December 2022

Source: *Chhattisgarh Environment Conservation Board, Monthly Progress Report, December 2022.*

The nature of hazardous waste generated in Chhattisgarh varies considerably among industrial sectors. Mineral and metallurgical industries generate residues containing metals, slag, dross and process-specific contaminants, while thermal-power and other energy-related activities generate ash-associated and oil-containing wastes. Cement and other process industries may generate waste oils, process residues and contaminated materials.

The major hazardous-waste streams identified by CECB include used/waste oil, oil sludge, cathode residues, tar residues, lead and zinc-bearing ash/slag/dross and sulphur sludge. For the Mahanadi basin industrial wastewater assessment, particular attention should be given to hazardous residues that originate directly or indirectly from wastewater-treatment processes. These include ETP sludge, metal-bearing sludge, spent treatment chemicals, oil-contaminated sludge and concentrated residues from advanced treatment systems.

Accordingly, hazardous-waste management should be integrated with the industrial wastewater management chain rather than treated as an independent waste-management activity.

The December 2022 CECB baseline reported no operational TSDF treatment capacity in the State. The same assessment recorded that establishment of a common hazardous-waste TSDF had been initiated through CSIDC. The proposed common facility is associated with Kesda Village in the Simga area of Baloda Bazar district. CECB has subsequently published environmental-clearance material for the proposed Common Hazardous Waste TSDF at Kesda, indicating continued development of this infrastructure.

TABLE 7 Preliminary Cluster-Wise Hazardous Waste Management Gaps – Chhattisgarh

Sl. No.	Industrial Cluster	Major Industrial Activities	Key Hazardous Waste Management Gaps
1	**Korba Industrial Cluster**	Thermal power, coal-based industries, aluminium and mineral-based industries	Management of ash-associated residues, waste oil, process residues and other hazardous streams; secure storage and final disposal
2	**Raigarh Industrial Cluster**	Steel, sponge iron, thermal power and mineral-based industries	Metal-bearing residues, slag/dross, waste oil and ETP-related hazardous sludge; recovery and secure disposal
3	**Siltara–Urla Industrial Cluster**	Steel, metal processing, engineering and manufacturing	Diverse hazardous waste streams, waste oils, metal-bearing residues and ETP sludge; improved segregation and authorized disposal
4	**Durg–Bhilai Industrial Cluster**	Steel, engineering and metal processing	Metal-bearing residues, oil-containing waste, process sludge and hazardous ETP residues; recovery and co-processing opportunities
5	**Bhanpuri–Rawabhata / Metal Park**	Metal processing and engineering	Metal-bearing sludge, slag/dross, contaminated materials and treatment residues; improved characterization and recovery
6	**Sirgitti–Tifra Industrial Cluster**	Engineering, manufacturing and MSMEs	Smaller and heterogeneous hazardous-waste streams, waste oils and ETP sludge; need for organized collection and authorized disposal
7	**Birkoni Industrial Area**	Manufacturing and industrial activities	Industry-specific hazardous residues and ETP sludge; verification of generation and disposal pathways

The development of common hazardous-waste infrastructure is important for the industrial clusters of the Mahanadi basin because it can provide a centralized mechanism for the treatment and secure disposal of hazardous residues generated by industries that do not have suitable on-site treatment or recovery options.

At the same time, the availability of a common facility should be complemented by **source-level waste minimization, segregation, recovery and co-processing**, so that only residues requiring secure disposal are ultimately sent to the TSDF.

The preliminary hazardous-waste management gaps for major industrial clusters in Chhattisgarh are presented in table 7.

The CECB's hazardous-waste framework already provides for authorization covering activities including generation, collection, storage, transportation, reception, reuse, recycling, recovery, co-processing, utilization, treatment and disposal.

4.2 Hazardous waste management in Odisha

Hazardous waste generated during industrial wastewater treatment may include hazardous sludge, metal-bearing residues, spent chemicals, oily sludge, concentrated RO rejects and other treatment residues. If improperly stored, transported or disposed of, these wastes can contaminate soil, groundwater and surface-water systems. Therefore, hazardous-waste management should be integrated with industrial wastewater treatment through source segregation, appropriate treatment, safe storage, authorized transportation and secure disposal. The major types of hazardous waste and treatment residues potentially associated with the major industrial clusters along the Mahanadi industrial corridor are summarized in Table 8.

TABLE 8 Types of Hazardous Waste Potentially Generated along the Mahanadi Industrial Corridor

Sl. No.	Industrial Cluster	Major Industrial Activities	Potential Hazardous Waste / Treatment Residues	Supporting Source
1	**Jharsuguda**	Aluminium, power and steel	Metal-bearing treatment sludge, spent oils, chemical-treatment residues and other sector-specific hazardous wastes	CPCB (2021); OSPCB (2023)
2	**Sambalpur–Hirakud**	Steel, engineering and associated industries	Pickling-related residues, oily sludge, metal-bearing residues and wastewater-treatment sludge	CPCB (2021); OSPCB (2023)
3	**Angul–Talcher**	Thermal power, aluminium, coal/mineral processing	Oil-contaminated sludge, treatment residues, ash-related residues and sector-specific hazardous wastes	CPCB (2021); OSPCB (2023)

4	**Cuttack–Choudwar–Jagatpur**	Chemical, engineering, food-processing and MSME activities	ETP sludge, paint/coating residues, spent solvents and metal-bearing treatment residues	CPCB (2021); OSPCB (2023)
5	**Paradeep–Mahanadi Delta**	Fertilizer, refinery, petrochemical and port-related industries	Oily sludge, spent catalysts, chemical-treatment sludge and other sector-specific hazardous residues	OSPCB (2023); MoEFCC (2016)

Source: *Compiled from CPCB (2021), OSPCB (2023), MoEFCC (2016), and relevant Odisha industrial/environmental planning documents.*

4.3 Treatment and Secure Landfill Needs

Industrial wastewater treatment can generate sludge, filter cakes, concentrated residues and other wastes that may require further treatment or authorized disposal. Therefore, wastewater-management planning should include a complete residual-waste management chain from generation to final disposal.

The management hierarchy should be:

Waste minimization → recovery/reuse → treatment → stabilization where required → authorized transport → TSDF/incineration/recovery → final disposal

Hazardous residues generated from industrial wastewater treatment should be characterized and managed according to their physical and chemical properties. Industries should first maximize resource recovery and reuse, followed by appropriate treatment and authorized disposal of residues that cannot be recovered.

Different industrial sectors require different treatment approaches. Steel and metallurgical industries may require oil separation, equalization, chemical precipitation and filtration for streams containing metals and oils. Fertilizer and chemical industries may require nutrient removal, chemical treatment and advanced treatment for ammonia, phosphates, nitrates and high-COD wastewater. Food-processing and other high-organic-load industries may require biological treatment followed by tertiary treatment and, where necessary, membrane or evaporation systems.

Hazardous sludge and non-recoverable treatment residues should be transported only through authorized systems to approved Treatment, Storage and Disposal Facilities (TSDFs) or secured landfill facilities. Secure disposal systems should incorporate engineered containment, leachate collection and groundwater monitoring to minimize the risk of pollutant migration.

Key requirements

- Characterization and classification of hazardous residues before disposal.
- Safe storage in designated and properly contained areas.
- Authorized transportation and documentation.
- Maximum feasible recovery of metals, chemicals and other valuable materials.
- Treatment/stabilization of hazardous residues before final disposal where required.
- Disposal only at authorized TSDF/secure-landfill facilities.
- Regular groundwater and environmental monitoring around disposal facilities.

4.4 Key Management Priorities

The following measures are recommended for the Chhattisgarh portion of the Mahanadi basin:

1. Establish an updated **GIS-based inventory of hazardous-waste-generating industries** within the basin.
2. Integrate hazardous-waste records with the **industry-wise wastewater and ETP database**.
3. Ensure characterization and proper classification of **ETP sludge and concentrated treatment residues**.
4. Strengthen source segregation and on-site storage of hazardous waste.
5. Promote authorized **recycling, recovery and co-processing** wherever technically and legally appropriate.
6. Ensure secure transportation and tracking of hazardous waste from industrial premises to authorized facilities.
7. Operationalise and strengthen common hazardous-waste treatment and disposal infrastructure.
8. Integrate hazardous-waste data with the State's digital environmental monitoring and consent-management systems. CECB currently provides online systems covering hazardous-waste applications and waste-management status, providing a foundation for such integration.
9. Establish a **basin-level industrial residual management framework** linking wastewater treatment, hazardous-waste generation, recovery and final disposal.

4.5 Strategy for Toxic Liquid Waste

Toxic and high-strength liquid wastes from industrial processes may contain heavy metals, toxic organic compounds, solvents and other hazardous constituents. Heavy metals such as chromium, cadmium, nickel, lead and mercury are persistent and potentially toxic to aquatic organisms and can accumulate in biological systems. Industrial wastewater may also contain mixtures of heavy metals and organic pollutants, making treatment more complex (Shrestha et al., 2021; Oladimeji et al., 2024).

The strategy should consist of four major components:

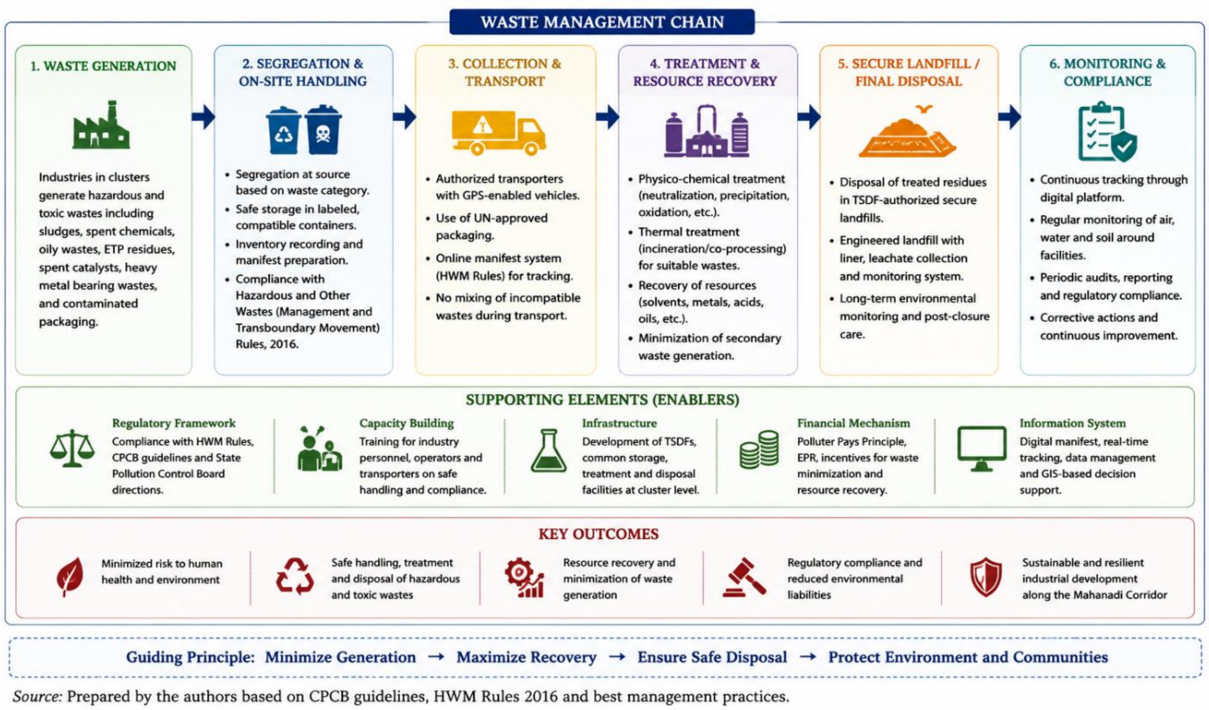
1. Source segregation
2. Treatment and recovery
3. Safe residual management
4. Monitoring and compliance

Toxic and high-strength wastewater streams should be segregated at source rather than mixing them with domestic sewage or low-strength industrial wastewater. Separate collection of high-TDS, heavy-metal, solvent-containing and other toxic streams improves treatment efficiency and reduces the overall treatment burden. Treatment should be selected according to the pollutant characteristics. Physical and chemical treatment may include screening, sedimentation, filtration, neutralization and precipitation. Membrane processes such as RO may be used for water recovery, while adsorption or advanced oxidation may be applied where persistent contaminants require additional treatment. Wherever technically feasible, valuable water, metals or chemicals should be recovered and reused.

Concentrated rejects, chemical sludge and other non-recoverable residues should not be discharged directly into rivers or drains. Where required, residues should undergo stabilization/solidification and be transferred to authorized secure-disposal facilities. Treated liquid effluent should be reused within the industry wherever feasible or discharged only when it complies with applicable regulatory requirements. Industries should maintain records of toxic-waste generation, treatment, storage, transportation and disposal. Regular monitoring should be undertaken for relevant parameters, and emergency-response procedures should be established for accidental spills, leaks or treatment-system failures.

Online wastewater monitoring should be integrated with hazardous-waste monitoring where appropriate, but OCEMS monitors effluent characteristics; it does not replace hazardous-waste tracking.

***Source:** Adapted from MoEFCC (2016), Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016.*



***Source:** Adapted from MoEFCC (2016), Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016*

Figure 9 Hazardous and Toxic Waste Management Chain for the Mahanadi Industrial Corridor.

4.6 Plan for continuous monitoring

A continuous and integrated monitoring system is essential for effective industrial wastewater management across the Mahanadi River Basin in Chhattisgarh and Odisha. The monitoring framework should integrate online industrial-effluent monitoring, river-water quality surveillance, high-risk pollutant monitoring, GIS-based data management and regulatory compliance mechanisms to enable early detection of pollution, timely corrective action and long-term protection of the river ecosystem.

The monitoring network should cover major industrial clusters and industrial estates in both States, together with associated drains, tributaries and receiving water bodies. In Chhattisgarh, priority should be given to the major industrial regions of Raipur–Siltara–Urla, Durg–Bhilai, Korba, Raigarh and Bilaspur, along with the identified polluted stretches of the Mahanadi, Kharun, Hasdeo, Kelo and Seonath. In Odisha, priority areas should include Jharsuguda, Sambalpur–Hirakud, Angul–Talcher, Cuttack–Choudwar–Jagatpur and Paradeep–Mahanadi Delta. The CECB baseline identifies Mahanadi, Kharun, Hasdeo, Kelo and Seonath among the polluted river stretches requiring continued monitoring in Chhattisgarh.

TABLE 9 Recommended Continuous Monitoring Framework for the Mahanadi Industrial Corridor

Monitoring Component	Key Parameters	Priority Locations
Industrial Outfall Monitoring	Flow, pH, BOD, COD, TSS	Red and Orange category industries in major industrial clusters of Chhattisgarh and Odisha
ETP Performance Monitoring	Flow, pH, BOD, COD, TSS, treatment efficiency	Major industries with individual ETPs and significant wastewater generation
High-Risk Industrial Monitoring	Heavy metals, TDS, conductivity, oil & grease and sector-specific pollutants	Korba, Raigarh, Siltara–Urla, Durg–Bhilai, Jharsuguda, Angul–Talcher and other high-risk clusters
River Water Monitoring	pH, DO, BOD, COD, TSS, turbidity, conductivity	Upstream and downstream of major industrial clusters and discharge locations
Industrial Drain/Outfall Monitoring	Flow, pH, BOD, COD, TSS, conductivity and relevant sector-specific parameters	Common industrial drains and identified discharge points
Tributary Monitoring	pH, DO, BOD, COD, TSS, conductivity and relevant pollutants	Kharun, Hasdeo, Kelo, Seonath, Ib and other tributaries receiving industrial influence
Mahanadi Main-Stem Monitoring	pH, DO, BOD, COD, TSS, conductivity and selected contaminants	Industrially influenced stretches in Chhattisgarh and Odisha
Estuarine/Coastal Monitoring	Salinity, conductivity, DO, BOD, COD and selected contaminants	Paradeep–Mahanadi Delta and tidal/estuarine zone
Hazardous Residual Monitoring	Quantity, characteristics, storage and disposal records	Major hazardous-waste-generating industrial clusters
Data Management	OCEMS data, laboratory data, GIS database, compliance records and automated alerts	Integrated CECB–OSPCB/CPCB monitoring platform

Source: *Adapted from CPCB, Central Water Commission, Ministry of Jal Shakti and State Pollution Control Board monitoring frameworks, with Chhattisgarh-specific industrial and river-stretch components incorporated into the basin-level framework.*

The monitoring framework should establish a clear upstream–industrial influence–downstream monitoring arrangement. This will enable differentiation between background water quality and pollution associated with industrial activities and will provide a basis for assessing cumulative impacts at cluster and basin levels. Further, following key monitoring actions are proposed for the basin.

- Install and maintain Online Continuous Effluent Monitoring Systems (OCEMS) at applicable Red and Orange category industries, with monitoring of flow, pH, BOD, COD and TSS and additional parameters such as TDS, conductivity, heavy metals and sector-specific pollutants wherever required.

- Establish upstream, industrial-influence and downstream river monitoring stations around major industrial clusters. In Chhattisgarh, priority should be given to the Mahanadi, Kharun, Hasdeo, Kelo and Seonath systems, while in Odisha monitoring should cover the major industrial stretches around Jharsuguda, Sambalpur–Hirakud, Angul–Talcher, Cuttack–Choudwar–Jagatpur and Paradeep.

- Establish monitoring points at common industrial drains and major outfalls to quantify cumulative industrial pollutant loads before they enter rivers or tributaries.

- Undertake targeted monitoring of high-risk pollutants, particularly heavy metals, TDS, conductivity, oil and grease and sector-specific contaminants in steel, aluminium, thermal-power, mining, chemical and other high-risk industrial clusters.

- Develop a centralized GIS-based Industrial Wastewater Monitoring Database integrating industry locations, ETPs, wastewater generation, OCEMS records, discharge points, river monitoring stations, water-quality results and regulatory compliance status.

- Integrate automated alerts for exceedance of prescribed standards, abnormal flow, sudden deterioration in effluent quality and prolonged ETP malfunction to facilitate timely regulatory intervention.

- Strengthen regulatory verification through periodic laboratory sampling, field inspection, instrument calibration and validation of OCEMS data by CECB, OSPCB and CPCB as applicable.

- Integrate industrial wastewater, hazardous-waste and river-water-quality data within the basin monitoring platform so that pollution sources, treatment performance and receiving-water impacts can be assessed together.

The proposed system will provide a transition from periodic, unit-level compliance monitoring towards a continuous, spatially integrated and basin-level industrial pollution management system, enabling coordinated assessment of industrial impacts across the Chhattisgarh and Odisha portions of the Mahanadi River Basin.

5. POLICY INTERVENTIONS

Effective industrial wastewater management along the Mahanadi River requires a coordinated policy framework integrating regulatory enforcement, pollution prevention, wastewater treatment, water reuse, ZLD, hazardous-waste management and continuous monitoring. Policy interventions should focus on reducing pollution at source, improving treatment performance, promoting water conservation and ensuring accountability of industrial units and responsible agencies.

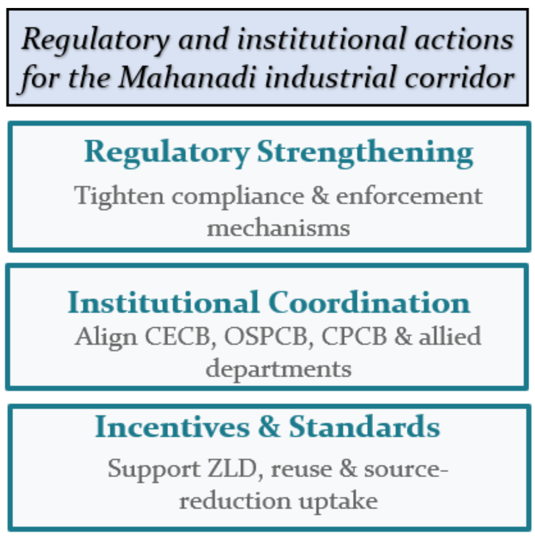


Figure 10. policy and institutional interventions

Key Policy Interventions

- **Strengthen regulatory compliance:** Ensure effective implementation of the *Water (Prevention and Control of Pollution) Act, 1974*, *Environment (Protection) Act, 1986* and applicable waste-management rules. Industries should maintain valid Consent to Establish and Consent to Operate and comply with prescribed effluent standards.
- **Improve ETP and CETP performance:** Require industries to properly operate and maintain ETPs and upgrade inadequate systems. CETPs should be promoted for suitable industrial clusters, particularly where small and medium industries cannot independently establish advanced treatment facilities.

- **Promote wastewater reuse and ZLD:** Encourage maximum reuse of treated wastewater for cooling, process applications, washing and other suitable purposes. ZLD should be prioritized for high-pollution and water-intensive industries where technically and economically feasible.
- **Strengthen online monitoring:** Applicable industries should install OCEMS and provide monitoring data to the regulatory authority. Online data should be periodically verified through laboratory testing and field inspections.
- **Establish integrated river monitoring:** Monitoring stations should cover upstream, industrial discharge and downstream locations. Parameters should include pH, DO, BOD, COD, TSS, conductivity, TDS and relevant heavy metals or sector-specific contaminants.
- **Strengthen hazardous-waste management:** Hazardous sludge, concentrated residues and other non-recoverable wastes should be safely stored, transported, treated and disposed of through authorized facilities in accordance with applicable hazardous-waste regulations.
- **Implement environmental accountability:** Non-compliance should result in appropriate corrective action and environmental compensation in accordance with applicable regulatory provisions. Industries should also maintain records of wastewater generation, treatment, reuse and disposal.
- **Strengthen institutional coordination:** OSPCB, CPCB, Water Resources Department, Industries Department, Urban Local Bodies and district administration should coordinate monitoring, enforcement, emergency response and implementation of cluster-level wastewater-management measures.
- **Establish industrial pollution emergency response:** Industries and regulatory agencies should maintain response plans for accidental spills, chemical releases, pipeline failures and treatment-system breakdowns, supported by periodic emergency drills.
- **Promote research and innovation:** Universities and research institutions should be encouraged to support advanced wastewater treatment, resource recovery, real-time monitoring, GIS-based assessment and AI-based pollution prediction.

6. ROLE OF STAKEHOLDERS

Effective industrial wastewater management along the Mahanadi River requires coordinated participation of regulatory authorities, industries, local communities and technical institutions.

Each stakeholder has a defined responsibility in pollution prevention, wastewater treatment, monitoring, compliance, emergency response and protection of river-water resources.

6.1 Regulatory Authorities

- **State Pollution Control Board:** Enforce environmental standards, issue and monitor consent conditions, inspect industries, verify OCEMS data and take action against non-compliance.
- **Central Pollution Control Board (CPCB):** Provide regulatory guidance, technical standards and national-level oversight for industrial pollution control and monitoring.
- **Water Resources Department:** Support water-resource planning, river-water management and protection of environmental water requirements.
- **Urban Local Bodies and District Administration:** Coordinate industrial and municipal pollution management, support local monitoring and facilitate emergency response.

6.2 Industrial Stakeholders

- **Industrial units:** Install, operate and maintain ETPs, wastewater-reuse systems and applicable ZLD systems in accordance with regulatory requirements.
- **High-polluting industries:** Implement source reduction, wastewater segregation, advanced treatment and maximum feasible water recovery.
- **Industries within clusters:** Participate in CETP and collective wastewater-management systems where individual treatment is not technically or economically feasible.
- **Mining and port operators:** Control contaminated runoff, spills, material storage and other pollution pathways that may affect tributaries and the Mahanadi estuary.
- **Industries should maintain:** records of wastewater generation, treatment, reuse, hazardous residues and compliance-monitoring data.

6.3 Local Communities and Other Stakeholders

- **Local communities:** Report visible pollution events such as abnormal colour, odour, fish mortality or suspected illegal discharge to the appropriate authorities.
- **Environmental organizations and NGOs:** Support environmental awareness, stakeholder participation and community-level monitoring.

- **Universities and research institutions:** Support development and evaluation of advanced wastewater-treatment technologies, real-time monitoring systems, GIS applications and pollution-prediction tools.

6.4 Stakeholder Coordination

A coordinated institutional mechanism should be established among CECB, OSPCB, CPCB, Water Resources Department, Industries Department, Urban Local Bodies, District Administration, industries, research institutions and local communities. Regular coordination meetings, data sharing, joint inspections and emergency-response mechanisms should be used to improve implementation and accountability.

The successful implementation of the Mahanadi industrial wastewater management plan depends on clearly defined responsibilities, effective institutional coordination and continuous stakeholder participation. Regulatory authorities should provide oversight and enforcement, industries should ensure pollution prevention and treatment at source, while local communities and civil-society organizations can contribute to environmental surveillance and awareness. Research institutions should provide scientific and technological support for monitoring, prediction, treatment and resource recovery. A coordinated stakeholder framework will strengthen accountability and facilitate long-term protection of the Mahanadi River system.

7. CONCLUSIONS

Industrial wastewater management in the Mahanadi River Basin across Chhattisgarh and Odisha requires an integrated basin-level approach that considers industrial cluster characteristics, wastewater generation and treatment, water conservation and reuse, Zero Liquid Discharge (ZLD) where applicable, hazardous-waste management, continuous monitoring and coordinated regulatory action. The assessment of industrial activities across both States demonstrates that wastewater-management requirements vary considerably depending on the type and scale of industrial activity, wastewater characteristics, water-use intensity, existing treatment infrastructure and the sensitivity of the receiving water environment.

The cluster-based approach provides an important framework for identifying priority areas for intervention. In Chhattisgarh, major industrial concentrations around Raipur–Siltara–Urla, Durg–Bhilai, Korba, Raigarh and Bilaspur, together with other industrial estates and clusters, require assessment at both individual-industry and cluster levels. In Odisha, major industrial concentrations around Jharsuguda, Sambalpur–Hirakud, Angul–Talcher, Cuttack–Choudwar–Jagatpur and Paradeep–Mahanadi Delta require similar assessment. The approach enables identification of locations where individual ETP improvement, common treatment systems, decentralized collection, advanced treatment and treated-water reuse may be appropriate.

At the industry level, the preferred management hierarchy should begin with source reduction, water conservation, wastewater segregation, process optimization and internal recycling, followed by appropriate treatment and reuse. Existing ETPs should be evaluated on the basis of actual hydraulic loading, treatment performance, operational reliability and compliance rather than installed capacity alone. Where wastewater characteristics and industrial concentration permit, CETPs may provide a viable collective-treatment option, particularly for compatible groups of small and medium industries. However, CETP development should be based on hydraulic, pollutant-load, wastewater-compatibility, conveyance, financial and institutional feasibility.

The assessment also highlights the importance of water recovery and reuse as a central component of sustainable industrial wastewater management. Treated wastewater should increasingly be considered as a potential alternative water resource for suitable non-potable and industrial applications. Cluster-level water balances can help identify opportunities for process-water recycling, cooling-water reuse and other applications, thereby reducing freshwater demand and minimizing liquid discharge.

Zero Liquid Discharge (ZLD) can provide an important pathway for water conservation and reduction of liquid effluent discharge in appropriate industrial sectors. However, ZLD should not be considered a uniform requirement for all industries. Its application should be based on sector-specific regulatory requirements, wastewater characteristics, water-recovery potential, receiving-water sensitivity and technical, environmental and economic feasibility. Management of RO rejects, concentrated streams, salts, sludge and other treatment residues should form an integral part of ZLD planning to prevent transfer of pollution from liquid effluent to secondary waste streams.

Hazardous-waste and treatment-residue management is another critical component of the basin-level strategy. ETP sludge, metal-bearing residues, waste oils, concentrated treatment residues and other hazardous wastes require appropriate characterization, segregation, storage, transportation, recovery, treatment and secure disposal. In Chhattisgarh, the CECB baseline reported 413 hazardous-waste-generating industries and approximately 172,437.78 tonnes/year of hazardous waste generation, highlighting the importance of strengthening residual-waste management alongside industrial wastewater treatment. The development and effective utilization of authorized treatment and disposal infrastructure, including TSDF facilities, should therefore be integrated into industrial environmental management in both States.

Continuous monitoring is essential for maintaining compliance and detecting industrial pollution incidents at an early stage. The recommended monitoring framework integrates OCEMS, industrial outfall monitoring, common-drain monitoring, river-water quality monitoring, GIS-based data management and periodic laboratory verification. Monitoring should establish upstream, industrial-influence/discharge-point and downstream locations around major industrial clusters. In Chhattisgarh, particular attention should be given to the Mahanadi and its identified polluted stretches including Kharun, Hasdeo, Kelo and Seonath, while in Odisha the monitoring network should cover major industrial stretches and the downstream and estuarine environment of the Mahanadi, including the Paradeep–Mahanadi Delta.

The basin-level approach is particularly important because the Mahanadi functions as a connected river system across Chhattisgarh and Odisha. Industrial pollution management in the upstream and middle reaches of Chhattisgarh has implications for downstream water quality, while industrial activities in Odisha influence the lower Mahanadi, delta and estuarine environment. Therefore, industrial wastewater management should move beyond isolated State- or industry-level compliance towards catchment-based assessment of cumulative pollutant loads and receiving-water impacts.

Effective implementation will require coordinated participation of the Chhattisgarh Environment Conservation Board (CECB), Odisha State Pollution Control Board (OSPCB), Central Pollution Control Board (CPCB), Water Resources Departments, Industries Departments, CSIDC, industrial-area authorities, Urban Local Bodies, district administrations, industries, research institutions and local communities. Coordination between the two States is particularly important for sharing industrial, wastewater and river-quality data and for identifying pollution sources and management priorities across State boundaries.

Overall, sustainable industrial wastewater management in the Mahanadi River Basin requires a transition from conventional pollution-control approaches towards integrated water-resource and pollution management. Source reduction, efficient treatment, water reuse, resource recovery, selective application of ZLD, responsible hazardous-waste management, continuous monitoring and coordinated regulatory action should form the core of the management strategy. Such an integrated approach can support both protection of the Mahanadi River ecosystem and sustainable industrial development across Chhattisgarh and Odisha.

8. RECOMMENDATIONS

Based on the proposed industrial wastewater-management framework and the assessment of industrial clusters in **Chhattisgarh and Odisha**, the following recommendations are proposed for the Mahanadi River Basin:

- **Strengthen basin- and cluster-level wastewater assessment** by maintaining an updated inventory of industries, industrial water consumption, wastewater generation, pollutant characteristics, existing ETP/CETP infrastructure, treated-water reuse and treatment gaps across both States.
- **Prioritize major industrial clusters** based on industrial concentration, wastewater generation, pollutant load, water consumption and receiving-water sensitivity. Priority areas should include **Korba, Raigarh, Raipur–Siltara–Urla, Durg–Bhilai and Bilaspur in Chhattisgarh**, and **Jharsuguda, Sambalpur–Hirakud, Angul–Talcher, Cuttack–Choudwar–Jagatpur and Paradeep–Mahanadi Delta in Odisha**.
- **Improve ETP performance** through regular operation and maintenance, periodic performance evaluation, process optimization, equipment upgradation and strengthening of monitoring systems. Assessment should consider actual hydraulic loading and treatment efficiency rather than installed capacity alone.
- **Develop CETPs where technically and economically feasible**, particularly in industrial clusters with a high concentration of compatible small and medium industries and where individual treatment systems are inadequate or economically difficult to upgrade.
- **Promote source reduction and wastewater segregation** at industrial premises to minimize wastewater generation, separate high-strength and incompatible streams and improve the efficiency of downstream treatment systems.

- **Increase treated-wastewater reuse and recycling** for suitable industrial applications, including process use, cooling, washing, gardening and other non-potable applications, thereby reducing freshwater abstraction and improving industrial water-use efficiency.
- **Promote cluster-level water balancing** to quantify freshwater intake, wastewater generation, treatment, reuse, recovery and final discharge and to identify opportunities for reducing net industrial water consumption.
- **Prioritize advanced treatment and ZLD** for industrial sectors and individual units where required by regulatory conditions or where technically, environmentally and economically justified. ZLD implementation should include appropriate management of concentrated rejects, salts, sludge and other treatment residues.
- **Strengthen hazardous-waste management** through proper characterization, source segregation, storage, transportation, recovery, treatment and authorized disposal of hazardous sludge, waste oils, metal-bearing residues, concentrated treatment residues and other regulated wastes.
- **Strengthen TSDF and secure-disposal infrastructure** based on actual hazardous-waste generation, existing treatment and disposal capacity, projected industrial growth and the spatial distribution of hazardous-waste-generating industries.
- **Establish an integrated continuous-monitoring network** covering industrial effluent, common industrial drains, upstream river locations, discharge/influence points and downstream receiving-water locations across the Chhattisgarh and Odisha portions of the basin.
- **Strengthen online monitoring and laboratory verification** through appropriate OCEMS installation, regular calibration, periodic laboratory sampling and independent verification of industrial-effluent and river-water-quality data.
- **Develop a centralized GIS-based industrial wastewater monitoring and decision-support system** integrating industrial locations, wastewater generation, ETP/CETP infrastructure, discharge points, OCEMS data, river-water quality, hazardous-waste records and regulatory compliance.

- **Establish an upstream–downstream monitoring framework** for priority industrial stretches to distinguish background water quality from industrial influence and assess changes in receiving-water quality downstream of industrial clusters.
- **Establish an industrial pollution emergency-response mechanism** for accidental spills, chemical releases, pipeline failures, ETP breakdowns, uncontrolled discharges and other pollution incidents, with clearly defined responsibilities and response procedures.
- **Strengthen coordination between Chhattisgarh and Odisha** for sharing industrial, wastewater and river-water-quality information, particularly for industrial activities and pollution sources that may influence downstream stretches of the Mahanadi system.
- **Strengthen institutional coordination** among **CECB, OSPCB, CPCB, Water Resources Departments, Industries Departments, CSIDC, industrial-area authorities, Urban Local Bodies, district administrations and industrial stakeholders** for implementation, monitoring and enforcement.
- **Promote research and technological innovation** in advanced wastewater treatment, water recovery, real-time monitoring sensors, resource recovery, pollution-load modelling, AI-based pollution prediction and appropriate nature-based treatment systems.
- **Establish measurable performance indicators** for industrial wastewater management, including wastewater treated, treatment compliance, percentage of treated wastewater reused, freshwater savings, pollutant-load reduction, hazardous waste safely managed, reduction in untreated discharge and improvement in receiving-water quality.
- **Develop cluster-specific management targets** based on wastewater generation, pollutant loads, treatment gaps, reuse potential and environmental sensitivity rather than applying uniform intervention targets across all industrial areas.
- **Undertake periodic review and updating of the management plan** to incorporate changes in industrial activity, industrial water demand, wastewater-generation patterns, treatment technologies, regulatory requirements, hazardous-waste infrastructure and receiving-water quality.

Overall, implementation of these recommendations should progressively shift industrial wastewater management in the Mahanadi Basin from conventional end-of-pipe pollution control towards integrated water conservation, treatment, reuse, resource recovery and receiving-water protection, with coordinated management across Chhattisgarh and Odisha.

References:

1. Central Pollution Control Board. (2015). *Guidelines on Zero Liquid Discharge (ZLD) for industries*. Ministry of Environment, Forest and Climate Change, Government of India.
2. Central Pollution Control Board. (2018). *Guidelines for real-time effluent monitoring systems*. Government of India.
3. Central Pollution Control Board. (2021). *General standards for discharge of environmental pollutants under the Environment (Protection) Rules, 1986*. Ministry of Environment, Forest and Climate Change, Government of India.
4. Central Pollution Control Board. (2021). *Guidelines for treatment, storage and disposal facilities for hazardous and other wastes*. Government of India.
5. Central Water Commission. (2022). *National Water Quality Monitoring Programme*. Ministry of Jal Shakti, Government of India.
6. Government of India. (1974). *The Water (Prevention and Control of Pollution) Act, 1974 (Act No. 6 of 1974)*. Government of India.
7. International Finance Corporation. (2007). *Environmental, health, and safety guidelines: General EHS guidelines*. World Bank Group.
8. Metcalf & Eddy/AECOM. (2014). *Wastewater engineering: Treatment and resource recovery* (5th ed.). McGraw-Hill Education.
9. Ministry of Environment, Forest and Climate Change. (1986). *Environment (Protection) Rules, 1986 (as amended)*. Government of India.
10. Ministry of Environment, Forest and Climate Change. (2016). *Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016*. Government of India.
11. Ministry of Environment, Forest and Climate Change. (2021). *Hazardous and Other Wastes (Management and Transboundary Movement) Amendment Rules, 2021*. Government of India.
12. Ministry of Jal Shakti. (2023). *National framework on safe reuse of treated used water*. Government of India.
13. NITI Aayog. (2018). *Composite water management index: A tool for water management*. Government of India.
14. Odisha State Pollution Control Board. (2010). *Action Plan for Abatement of Pollution in Critically Polluted Industrial Cluster: Angul–Talcher / Ib Valley–Jharsuguda*. Government of Odisha.

15. Odisha State Pollution Control Board. (2021). *Action Plan for Abatement of Pollution in Industrial Areas of Paradeep*. Government of Odisha.
16. Odisha State Pollution Control Board. (2023). *Annual Report 2022–23*. Government of Odisha.
17. Oladimeji, T. E., Oyedemi, M., Emetere, M. E., Agboola, O., Adeoye, J. B., & Odunlami, O. A. (2024). Review on the impact of heavy metals from industrial wastewater effluent and removal technologies. *Heliyon, 10*(23), e40370. https://doi.org/10.1016/j.heliyon.2024.e40370
18. Padalkar, A. V., & Kumar, R. (2018). Common effluent treatment plant (CETP): Reliability analysis and performance evaluation. *Water Science and Engineering, 11*(3), 205–213. https://doi.org/10.1016/j.wse.2018.10.002
19. Panda, S., Patra, A. K., & Mohanty, S. K. (2012). Impact of industrial activities on River Mahanadi near Jagatpur Industrial Estate: A case study. *Asian Journal of Water, Environment and Pollution, 9*(3), 79–81. https://doi.org/10.3233/AJW-2012-9_3_13
20. Pany, R., Rath, A., & Swain, P. C. (2023). Water quality assessment for River Mahanadi of Odisha, India using statistical techniques and Artificial Neural Networks. *Journal of Cleaner Production, 417*, 137713. https://doi.org/10.1016/j.jclepro.2023.137713
21. Pathe, P. P., Suresh Kumar, M., Kharwade, S., & Kaul, S. N. (2004). Common effluent treatment plant (CEPT) for wastewater management from a cluster of small-scale tanneries. *Environmental Technology, 25*(5), 555–563.
22. Shrestha, R., Ban, S., Devkota, S., Sharma, S., Joshi, R., Tiwari, A. P., Kim, H. Y., & Joshi, M. K. (2021). Technological trends in heavy metals removal from industrial wastewater: A review. *Journal of Environmental Chemical Engineering, 9*(4), 105688. https://doi.org/10.1016/j.jece.2021.105688
23. Ghumra, D. P., Agarkoti, C., & Gogate, P. R. (2021). Improvements in effluent treatment technologies in Common Effluent Treatment Plants (CETPs): Review and recent advances. *Process Safety and Environmental Protection, 147*, 1018–1051.
24. Fu, F., & Wang, Q. (2011). Removal of heavy metal ions from wastewaters: A review. *Journal of Environmental Management, 92*(3), 407–418.
25. Kurniawan, T. A., Chan, G. Y. S., Lo, W. H., & Babel, S. (2006). Physico-chemical treatment techniques for wastewater laden with heavy metals. *Chemical Engineering Journal, 118*(1–2), 83–98.

26. Gautam, R. K., Mudhoo, A., Lofrano, G., & Chattopadhyaya, M. C. (2014). Biomass-derived biosorbents for metal ions sequestration: Adsorbent modification and activation methods and adsorbent regeneration. *Journal of Environmental Chemical Engineering, 2*(1), 239–259.
27. UNESCO World Water Assessment Programme. (2023). *The United Nations World Water Development Report 2023: Partnerships and cooperation for water*. UNESCO.

cMahanadi

cGanga