Project Report

Wastewater Inventorisation and Review of National Practice for reporting GHG emissions from wastewater

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Report on Wastewater Inventorisation and Review of National Practice for reporting GHG emissions from wastewater

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TABLE OF CONTENT

Contents

List of Figures

List of Tables

List of Annexures

ABREVIATIONS USED

AR2	IPCC Second Assessment Report
ASP	Activated Sludge Process
BORDA	Bremen Overseas Research and Development Association
BUR1	India's First Biennial Update Report
BUR2	India's Second Biennial Update Report
BUR3	India's third Biennial Update Report
CAGR	Cumulative Annual Growth Rate
CO2e	Carbon di oxide equivalent
CPCB	Central Pollution Control Board
DEWATS	Decentralized Wastewater Treatment Systems
DWW	Domestic Wastewater
EA	Extended Aeration
FAB	Fluidized Aerobic Bed Reactor
GHG	Green House Gases
GHGPI	GHG Platform India
GWP	Global Warming Potential
INCCA	Indian Network for Climate Change Assessment
IPCC	Intergovernmental Panel on Climate Change
IWW	Industrial Wastewater
LB	Local Bodies
MBBR	Moving Bed Biofilm Reactor

MLD	Millon Liter per Day
MoEF&CC	Ministry of Environment Forest & Climate Changa
NCT	National Capita Territory
NGO	Non-Government Organization
NGT	National Green Tribunal
OP	Oxidation Pond
PCC	Pollution Control Company
SBR	Sequencing Bed Reactor
SPCB	State Pollution Control Board
STP	Sewage Treatment Plant
UASB	Up flow Anaerobic Sludge Bed
ULB	Urban Local Body
UNFCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
UT	Union Territory
WSP	Waste Stabilization Pond
WW	Wastewater
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

India, a nation with a population that has surged from 683.33 million in 1981 to an astounding 1.31 billion in 2021, faces an immense challenge in managing its wastewater. As per CPCB, the daily generation of sewage is about 72,368 million liters. While there exists an installed capacity of 31,841 million liters per day (MLD) distributed across 1,469 sewage treatment plants (STPs), the operational capacity, standing at 26,869 MLD and spread across 1,093 STPs, reveals a significant gap between potential and actual utilization, out of which only 20,235 MLD being effectively utilized. India's top 10 states in terms of sewage generation include Maharashtra, Gujarat, Uttar Pradesh, NCT Delhi, Karnataka, Haryana, Madhya Pradesh, Punjab, Tamil Nadu, and Rajasthan.

Cumulatively, the Waste sector in India projected greenhouse gas (GHG) emissions of 114.50 million tonnes CO_2 equivalent in 2018. Notably, the domestic wastewater treatment and discharge sector stands out as the primary source of GHG emissions, accounting for a significant 55.7% of total emissions from waste sector in 2018. The emissions stemming from the domestic wastewater sector exhibit a noteworthy trend, increasing from 43.82 million tonnes of CO_2e in 2005 to a substantial 63.76 million tonnes in 2018. This indicates a Compound Annual Growth Rate (CAGR) of 2.93%, revealing the sector's growing environmental impact. Furthermore, GHG emission forecasts for the years 2019 to 2025 consistently portray an upward trajectory, with projected values spanning from 67.62 to 78.38 million tonnes tCO_2e by 2025.

However, there's a gap between the estimates provided by the Global Greenhouse Gas Program of India (GHGPI) and those submitted to the Intergovernmental Panel on Climate Change (IPCC) by the Ministry of Environment, Forest and Climate Change (MoEF&CC), Government of India. These differences are substantial, with figures varying by 64.2% for 2016, 63.6% for 2014, 60.10% for 2010, and a staggering 96.8% for 2007. This contrast raises a need to do a thorough study of the methodologies used by both organizations to reach on the estimates.

While GHGPI follows IPCC guidelines and has clearly defined the methodology, emission factors, and data sources when estimating GHG emissions from the wastewater sector, the Indian government's biennial reports lack detailed explanations regarding the methods and data used for the reported estimates.

To resolve these disparities, it's imperative to engage in extensive discussions and cooperation with relevant stakeholders. Additionally, a thorough assessment of the government's methodology is required. Accurate reporting and the development of effective strategies to mitigate GHG emissions hinge on gaining a deep understanding of the factors contributing to these inconsistencies in data reporting.

INTRODUCTION

India, as one of the world's most populous nations, faces substantial challenges related to wastewater management. The country tops in wastewater generation amongst the South Asian Countries. According to a recent assessment by Central Pollution Control Board (CPCB) in 2020-21, about 72,368 million Liter Per day (MLD) of sewage is generated out of which only 20,236 MLD (28%)[1] is effectively treated. The rest 72% of wastewater finds its way to lakes, rivers, open drains and groundwater, ultimately leading to contamination of available resources. Recognizing the urgency of this situation, India has been making substantial investments in expanding its wastewater treatment infrastructure to bridge this significant treatment gap.

Wastewater treatment facilities represent a significant source of anthropogenic greenhouse gas emissions, as outlined by the U.S. Environmental Protection Agency (USEPA) in 1997. Within these treatment processes, three prominent greenhouse gases—carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)—are generated. These gases originate from various mechanisms, including aerobic microbial degradation and the combustion of organic matter, anaerobic degradation of organics, and nitrification and denitrification processes responsible for CO_2, CH_4, and N_2O emissions, respectively[2]. In this context, the importance of understanding and mitigating greenhouse gas (GHG) emissions from the wastewater treatment sector in India cannot be overstated. This is because the process of treating wastewater leading release of GHGs into the atmosphere from collection and treatment facilities contributes to climate change. Hence, addressing GHG emissions in the wastewater sector is pivotal not only for India's environmental sustainability but also for its commitment to combat climate change at the global arena and accurate GHG inventories in this sector are crucial for understanding its contribution to India's overall emissions profile and for developing effective mitigation strategies. The Intergovernmental Panel on Climate Change (IPCC) has issued a comprehensive set of guidelines designed to facilitate the estimation of greenhouse gas (GHG) emissions and assist in the development of effective strategies for mitigating global climate change.

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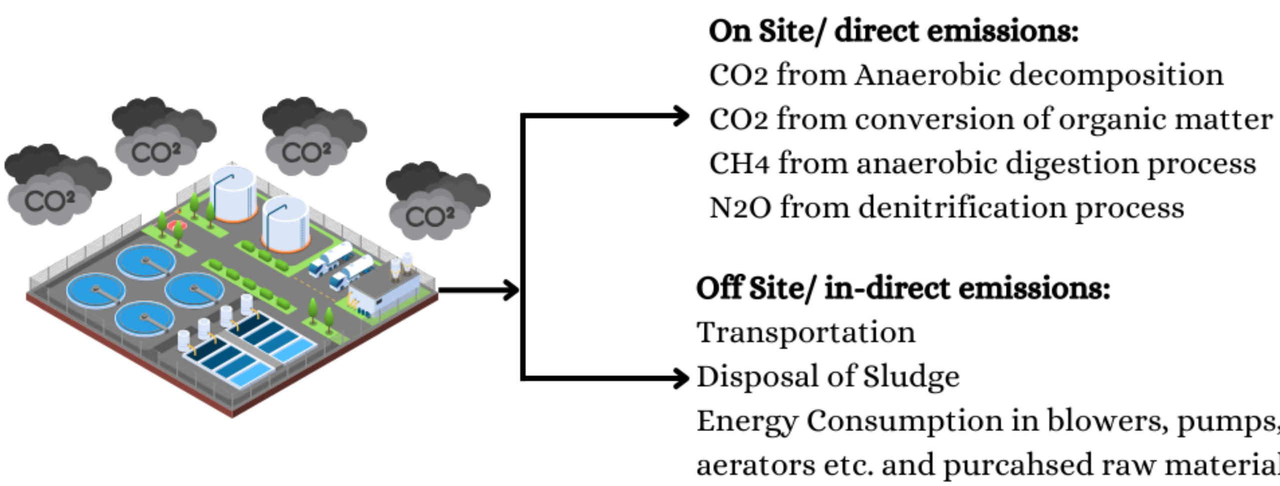
[1] CPCB Sewerage Data of India, 2021, accessed on 10th September 2023

[2] Vipin Singh, Harish C. Phuleria & Munish K. Chandel, Estimation of greenhouse gas emissions from municipal wastewater treatment systems in India, 2017, 1747-6585

Types of GHG Emission & Potential Sources

The GHG emissions from wastewater treatment sector are categorized into On-site and off-site emission[3]. A few researchers have also termed the same Direct & Indirect emissions[4].

- **On-site/ direct GHG emissions**: The emissions of GHG during the treatment of wastewater as well as during the treatment process of sludge and for onsite energy generation. Direct GHG emissions from STP are mainly CO_2 from the aerobic decomposition and conversion of organic matter in the biological treatment process, CO_2 and CH_4 from the anaerobic digestion process, N_2O from the denitrification process.
- **Off-site/ Indirect GHG emissions:** The emissions generated due to transportation (Fuel consumed), disposal of sludge, energy consumption in blowers, pumps, aerators etc. and purchased raw material.



Global Warming Potential

The IPCC has developed the concept of Global Warming Potential (GWP) for comparing the ability of each of the GHG to trap heat in the atmosphere relative to another gas. According to USEPA "*Global Warming Potential (GWP) is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2). The larger the GWP, the more that a given gas warms the Earth compared to CO_2 over that time-period. The time-period usually used for GWPs is 100 years*". The CO_2, CH_4,

[3] G. Vijayan, R. Saravanane, T. Sundararajan, Carbon Footprint Analyses of Wastewater Treatment Systems in Puducherry, 2017, 6, 281-303

[4] Lin Lin, Carbon emission assessment of wastewater treatment plant based on accounting perspective, 194, 04049 (2020)

N_2O and other greenhouse gases emitted by the sewage treatment plant are uniformly measured by the amount of CO_2 produced.

Project Objective:

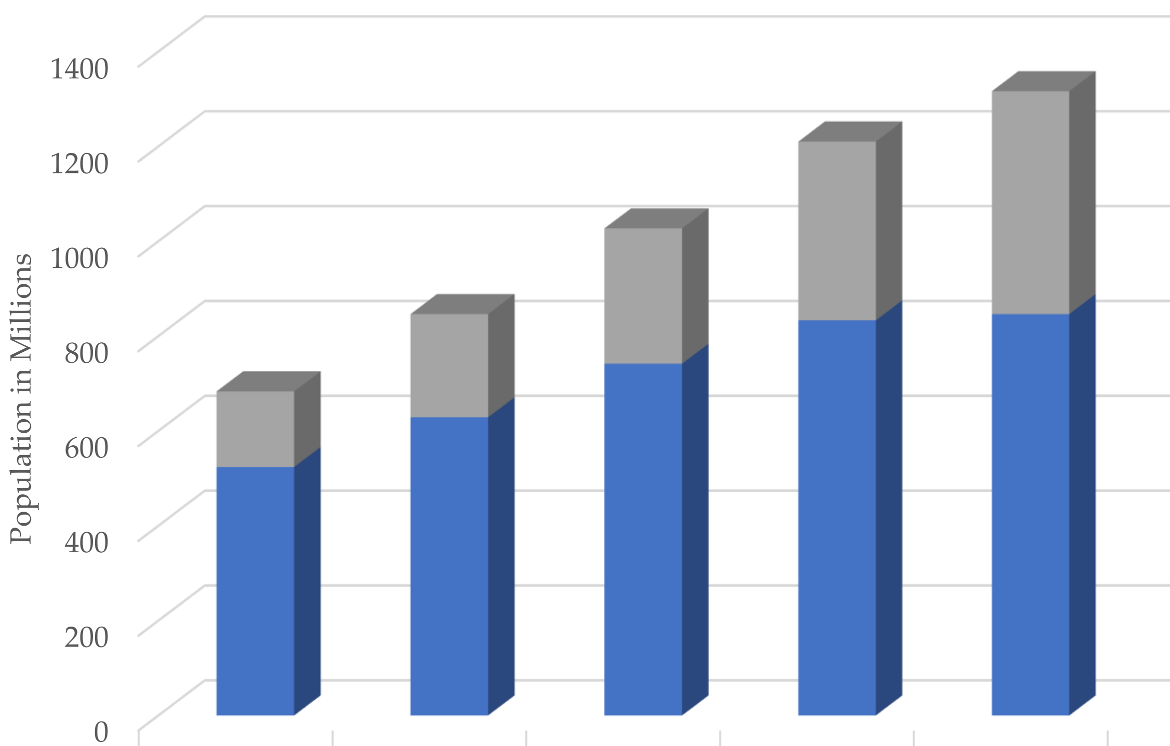
The primary objectives of the project are as follows:

- Study wastewater Ecosystem in the country
- Inventorize the centralized & decentralized wastewater treatment plant
- Identification of WW value chain
- Summarize emission sources of GHG across WW value chain
- Quantify the emissions from domestic wastewater sector in India
- Analyze existing reporting methodologies employed by the Government of India and identify opportunities for improvement by comparing it with IPCC methodology.
- Offer recommendations aimed at improving the precision and comprehensiveness of GHG emission estimation.

WASTEWATER ECOSYSTEM IN INDIA

Population

Over the past four decades, India has experienced profound demographic changes. In 1981, the country's population was approximately 683.33 million, with a predominantly rural composition. However, the subsequent years witnessed a notable surge in urbanization, culminating in a significant milestone in 2011 when India's total population crossed 1.21 billion, with over 377.1 million residing in urban areas. As of 2021, urbanization continued to rise, with 469.9 million living in urban centers, while the rural population remained relatively stable at 846.4 million, resulting in a total population of 1.31 billion. These demographic shifts have far-reaching implications for infrastructure development, water resource management, wastewater generation and urban planning in India**.**



	1981	1991	2001	2011	2021
Urban	159.46	217.61	285.35	377.11	469.93
Rural	523.87	628.69	741.66	833.09	846.42

Figure 1: Indian Rural, Urban and Total Population

Wastewater Generation:

India tops in wastewater generation amongst the South Asian Countries. The wastewater scenario in India reveals a significant disparity between sewage generation and the country's wastewater treatment capacity. India generates a massive 72,368 million liters per day (MLD) of sewage, highlighting the immense challenge of managing wastewater in a densely populated nation. While there is an installed capacity of 31,841 MLD distributed across 1,469 sewage treatment plants (STPs), the operational capacity stands at 26,869 MLD across 1,093 STPs[5]. However, the actual utilization of this capacity is notably lower, at 20,235 MLD. This data underscores the pressing need for infrastructure expansion, efficiency improvements, and sustainable wastewater management practices to bridge the gap between sewage generation and treatment capacity.

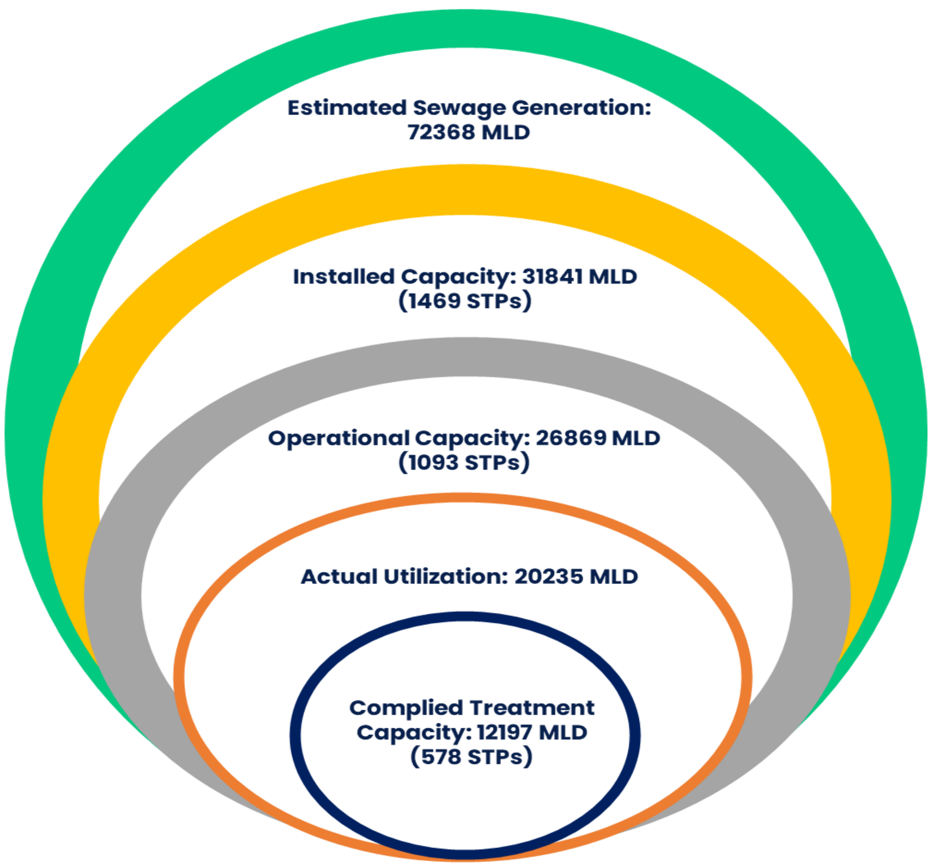


Figure 2: Venn Diagram of Wastewater Scenario in India[5]

[5] CPCB Sewerage Data of India, 2021

STP Inventory

Central Pollution Control Board published the national inventory of Sewage Treatment Plants in India in March 2021. This report has been prepared based on the data provided by State Pollution Control Boards (SPCBs)/ Pollution Control Committees (PCCs) and Local Bodies (LBs).

- State-wise sewage generation and treatment capacity is presented in Annexure A. Whereas here in table 1, The top 10 states and Union Territories (UTs) in India with the highest sewage generation (in the decreasing order), number of STPs installed, cumulative capacity of STPs and Sewage treatment capacities is given.

Table 1: Top 10 States in Sewage Generation[6]

Sr No	State / UTs	Total Sewage Generation (MLD)	Number of STPs Installed	Cumulative Capacity of STPs in MLD	Sewage Treatment Capacity as percentage of total Sewage Generation
1	Maharashtra	9107	154	6890	76%
2	Uttar Pradesh	8263	107	3374	41%
3	Tamil Nadu	6421	63	1492	23%
4	West Bengal	5457	50	897	16%
5	Gujarat	5013	70	3378	67%
6	Karnataka	4458	140	2712	61%
7	Kerala	4256	7	120	3%
8	Madhya Pradesh	3646	126	1839	50%
9	NCT Delhi	3330	38	2896	87%
10	Rajasthan	3185	114	1086	34%

From the list it is evident that Maharashtra has highest sewage generation and yet 76% sewage treatment capacity, whereas UP which falls at the second place in sewage generation, has a very less share of around 41% sewage treatment capacity, highlighting proactive approach in Maharashtra as compared to UP in sewage treatment.

Tamil Nadu, another state with notable sewage generation, faces a similar challenge, with a treatment capacity covering only 23% of its generated sewage.

States like Kerala are in dire need of infrastructure development, as they possess just 3% sewage treatment capacity relative to their sewage generation. The National Capital Territory (NCT) of Delhi, despite its relatively smaller geographical area, generates 3,330

[6] National Inventory of Sewage Treatment Plants, CPCB, March 2021

MLD of sewage, backed by 38 STPs with a cumulative capacity of 2,896 MLD, resulting in an impressive sewage treatment capacity of 87%.

A comprehensive snapshot of sewage treatment infrastructure in top ten sewage generating Indian states is given in Table 2, detailing the number and capacity (in MLD) of existing STPs as well as the proposed new STPs in these states.

Table 2: Categorization of STPs of top 10 sewage generating states into Operational, Non-Operation & Under Construction7

#	State	Number / Capacity in MLD	Installed (1)	New Proposed (2)	Total Capacity (1+2)	Operational	Non-Operational	Under Construction
1	Maharashtra	Nos.	154	41	195	130	7	17
		Capacity (MLD)	6890	2929	9819	6366	243	281
2	Uttar Pradesh	Nos.	107	0	107	99	8	0
		Capacity (MLD)	3374	0	3374	3224	150	0
3	Tamil Nadu	Nos.	63	0	63	63	0	0
		Capacity (MLD)	1492	0	1492	1492	0	0
4	West Bengal	Nos.	50	15	65	24	13	13
		Capacity (MLD)	897	305	1202	337	324	236
5	Gujarat	Nos.	70	0	70	69	1	0
		Capacity (MLD)	3378	0	3378	3358	20	0
6	Karnataka	Nos.	140	0	140	97	32	11
		Capacity (MLD)	2712	0	2712	1922	323	467
7	Kerala	Nos.	7	0	7	3	4	0
		Capacity (MLD)	120	0	120	114	6	0
8	Madhya Pradesh	Nos.	126	16	142	45	3	78
		Capacity (MLD)	1839	85	1924	684	22	1133
9	NCT Delhi	Nos.	38	0	38	35	3	0
		Capacity (MLD)	2896	0	2896	2715	181	0
10	Rajasthan	Nos.	114	26	140	57	10	47
		Capacity (MLD)	1086	109	1195	783	41	262

Treatment Technology Used

The carbon emissions in wastewater treatment depends upon the type of technology used primarily because different treatment processes involve various stages and mechanisms,

[7] National Inventory of Sewage Treatment Plants, CPCB, March 2021

each with its own carbon footprint. Different technologies are utilized for the treatment of domestic wastewater, and among these, SBR and ASP stand out as the most commonly adopted technologies by ULBs. The distribution of these technologies in STPs is detailed in Figure 3.

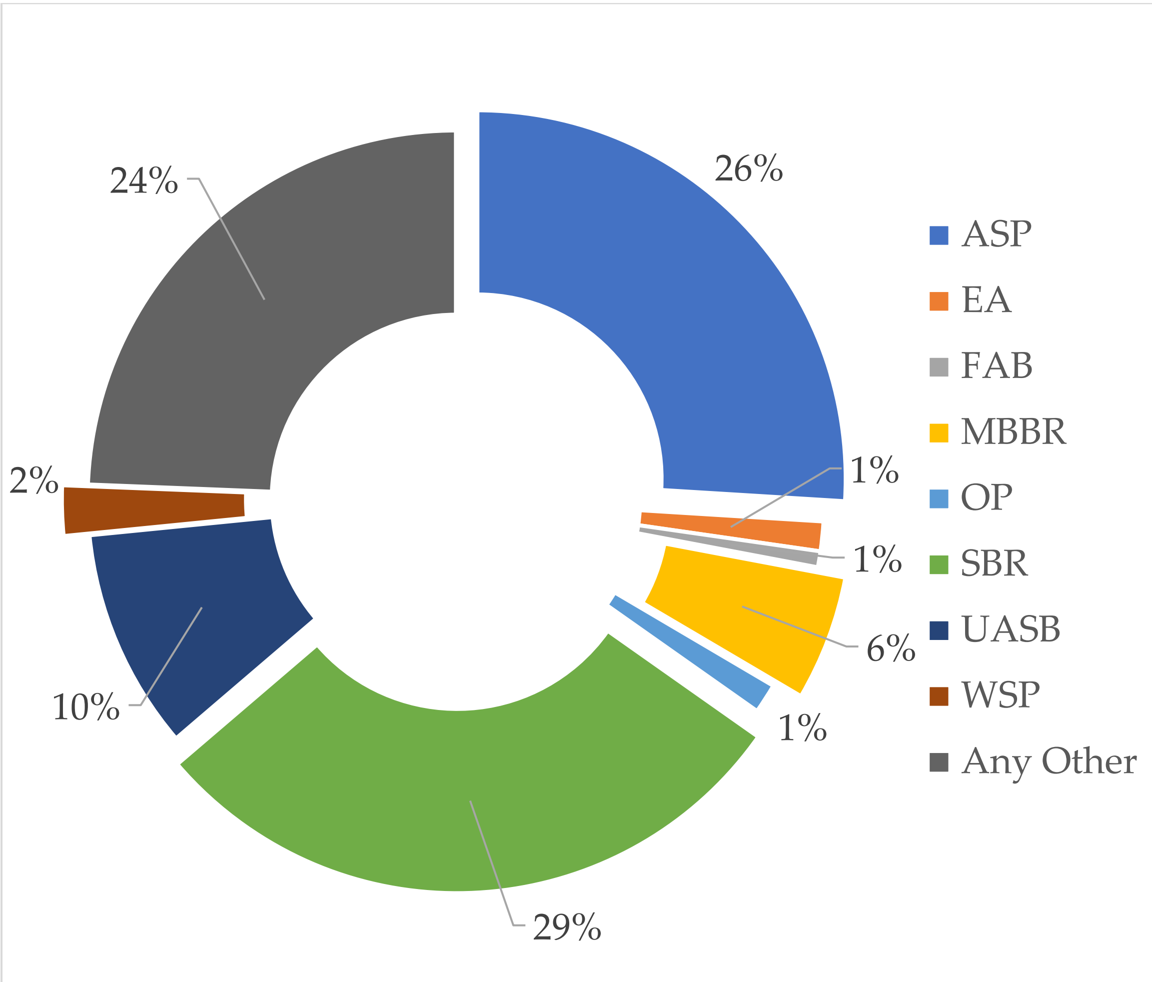


Figure 3: Percentage of Technology in comparison to Installed + Proposed Capacity (Nationally)[8]

[8] National Inventory of Sewage Treatment Plants, CPCB, March 2021

ASP	Activated Sludge Process	**UASB**	Upflow Anaerobic Sludge Blanket
EA	Extended Aeration	**WSP**	Waste Stabilization Pond
FAB	Fluidized Aerobic Bed Reactor	**Any Other**	Aerated Lagoon, Trickling Filter, Bio-Tower, Electro Coagulation, Membrane Bioreactors, Fluidized Media Bio Reactor and Root Zone etc.
MBBR	Moving Bed Biofilm Reactor		
OP	Oxidation Pond		
SBR	Sequencing Batch Reactor		

Based on data, the majority of treatment capacity is attributed to Sequential Batch Reactor (SBR) technology, accounting for a significant 29% of the total capacity. Activated Sludge Process (ASP) also plays a substantial role, constituting 26% of the total capacity, highlighting its prevalence in sewage treatment infrastructure. Other notable contributors include Up flow Anaerobic Sludge Blanket (UASB) at 10%, Moving Bed Biofilm Reactor (MBBR) at 6%, and Waste Stabilization Ponds (WSP) at 2%. State-wise distribution of technologies used for wastewater treatment is given in Annexure B.

The top 10 sewage generating state-wise breakdown of technological distribution based on installed capacity is summarized in Table 3, which provides a comprehensive overview of the prevalence of specific wastewater treatment technologies in various regions, aiding in the assessment of technology adoption patterns.

Table 3: Technologies Installed in Top 10 Sewage Generating States[9]

#	State	Number / Capacity in MLD	ASP	EA	FAB	MBBR	OP	SBR	UASB	WSP	Any Other
1	Maharashtra	Nos.	24	7	1	35	2	75	6	0	45
		Capacity (MLD)	930	146	1	826	36	2452	240	0	5188
2	Uttar Pradesh	Nos.	20	0	4	3	14	31	24	3	8
		Capacity (MLD)	681	0	122	14	101	1176	1095	27	158
3	Tamil Nadu	Nos.	49	0	1	0	1	5	1	2	4
		Capacity (MLD)	1011	0	6	0	6	319	9	112	29
4	West Bengal	Nos.	10	0	2	0	9	21	0	8	15
		Capacity (MLD)	191	0	41	0	63	392	0	160	355
5	Gujarat	Nos.	14	4	0	5	8	24	7	0	8
		Capacity (MLD)	1254	60	0	175	46	1285	491	0	67
6	Karnataka	Nos.	12	9	2	2	14	43	2	10	46
		Capacity (MLD)	667	166	20	35	85	1079	63	61	536
7	Kerala	Nos.	4	0	0	0	0	0	0	0	3
		Capacity (MLD)	112	0	0	0	0	0	0	0	8

[9] National Inventory of Sewage Treatment Plants, CPCB, March 2021

8	Madhya Pradesh	Nos.	4	0	0	0	0	6	0	7	125
		Capacity (MLD)	120	0	0	0	0	358	0	178	1268
9	NCT Delhi	Nos.	28	4	1	0	0	4	0	0	1
		Capacity (MLD)	2575	69	3	0	0	245	0	0	4
10	Rajasthan	Nos.	15	0	0	11	2	79	5	15	13
		Capacity (MLD)	445	0	0	10	30	428	33	137	112
	Total	**Nos.**	**180**	**24**	**11**	**56**	**50**	**288**	**45**	**45**	**268**
		Capacity (MLD)	**7986**	**441**	**193**	**1060**	**367**	**7734**	**1931**	**675**	**7725**

DEWATS in India

DEWATS, or Decentralized Wastewater Treatment Systems, represents an efficient and cost-effective solution for wastewater management, particularly in developing countries like India. It holds significant potential for establishing sustainable long-term environmental sanitation systems. DEWATS involves treating, releasing, or reusing wastewater near its source and can treat both domestic and industrial wastewater with treatment level ranging for organic wastewater flows from 1 to 1000 m^3/day[10].

In numerous developing countries like India, large cities typically have centralized sewage and wastewater treatment systems, but smaller towns and densely populated, low-income urban areas often lack adequate coverage. In these densely populated areas and slums, centralized solutions can prove difficult to implement, leading to the need for supplementary wastewater treatment approaches. DEWATS, which can be integrated with simplified sewer systems or community sanitation facilities, play a crucial role in bridging the gap between on-site sanitation and centralized wastewater treatment systems.

Sustainable decentralized sanitation primarily addresses the treatment of relatively small volumes of wastewater originating from individual households or clusters of closely located residences. This typically applies to areas within a radius of about 3 kilometers, including peri-urban development clusters that are not yet connected to a central sewer system linked to a regional wastewater treatment plant (WWTP). In case of any issues, the impact is limited to the specific cluster being served. The key distinction between decentralized and centralized systems lies in how the treated wastewater is managed. In decentralized systems, treatment, disposal, or reuse of the treated water occurs close to where it is generated, resulting in a smaller conveyance network. This approach can

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[10] V. Geeta Verma et. al. A review on decentralized wastewater treatment systems in India, 2022, 300 (2022) 134462

facilitate the implementation of local non-drinking water reuse programs within a community.

The Bremen Overseas Research and Development Association (BORDA) is a nongovernment organization (NGO) working for over four decades in the field of sanitation and urban development.

While there is no concrete data on number of DEWATS in India, 77 BORDA DEWATS plants that were set up until the year 2017. Out of the total plants, 11 and 56 plants have been funded by Government and Private organizations respectively[11]. These plants are designed to treat wastewater in an eco-friendly way. The list of these DEWATS plants is attached in Annexure C, whereas Figure 4 presents a timeline of DEWATS establishments in India, detailing the number of plants initiated each year from 1989 to 2019.

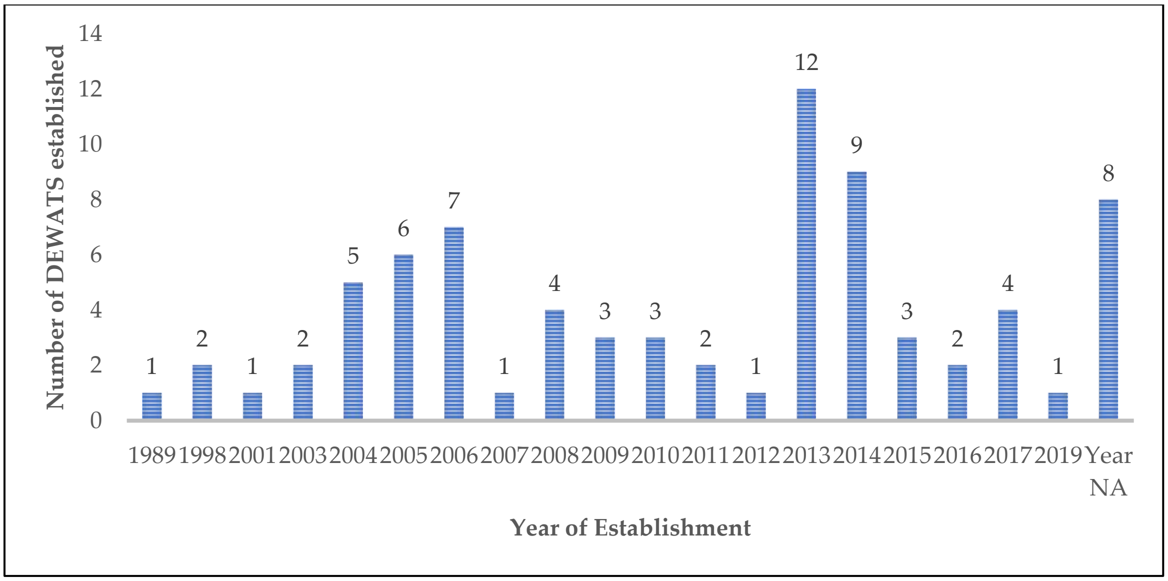

Figure 4: Inventorization of DEWATS in terms of Establishment Year

Figure 4 presents a timeline of DEWATS establishments in India, detailing the number of plants initiated each year from 1989 to 2019. The trend showcases scattered growth over the years. The early years saw limited progress, however, a notable increase occurred from 2004, with the establishment of 5 plants, and subsequent years witnessed a steady rise, reaching a peak of 12 plants in 2013. This period indicates a heightened focus on DEWATS, possibly driven by environmental concerns and the need for sewage treatment. There's a gap in data for the year NA.

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[11] Anju Singh et.al. Performance evaluation of a decentralized wastewater treatment system in India, 2019, 26:21172–21188

WASTEWATER TREATMENT VALUECHAIN

The wastewater value chain refers to the different stages involved in the management of wastewater, from its generation to its treatment and eventual disposal or reuse. The typical chain consists of four main stages: collection, treatment, discharge, and reuse. In the first stage, wastewater is collected from households, industries, and other sources through sewer systems. The collected wastewater is then transported to treatment plants where it undergoes a series of treatment processes to remove pollutants and contaminants. Once treated, the water is discharged into rivers, lakes, or oceans or reused for various purposes such as irrigation or industrial processes. Throughout this value chain, there are several sources of greenhouse gas (GHG) emissions. Here's a description of the wastewater management system and the associated sources of GHG emissions:

1. **Collection and Conveyance:** The value chain begins with the collection and conveyance of wastewater from various sources, including households, industries, and businesses. GHG emissions in this stage can occur due to energy consumption for pumping and transporting wastewater through sewer systems. Energy-intensive pumping stations can contribute to carbon emissions.

2. **Primary Treatment:** In this phase, large solids and debris are removed from the wastewater. While primary treatment itself doesn't generate significant GHGs, the energy used for mechanical processes like screening and sedimentation can lead to emissions.

3. **Secondary Treatment**: Secondary treatment aims to remove dissolved and suspended organic matter from the wastewater. The most common secondary treatment methods are activated sludge, extended aeration, and sequencing batch reactors (SBRs). GHG emissions primarily occur in this phase due to aeration processes. The breakdown of organic matter in the presence of oxygen generates carbon dioxide (CO_2) emissions and N_2O during the denitrification process. Additionally, the release of methane (CH_4) can occur in anaerobic conditions, such as in sludge digesters.

4. **Tertiary Treatment**: Tertiary treatment involves further polishing of the effluent to remove nutrients like nitrogen and phosphorus. While this phase may require additional energy for chemical dosing or filtration, GHG emissions are generally lower compared to secondary treatment.

5. **Sludge Handling**: Handling and managing the sludge produced during wastewater treatment is a significant source of GHG emissions. Anaerobic digestion of sludge can produce methane, a potent greenhouse gas. If not captured and utilized, methane emissions from sludge can contribute to global warming. Sludge disposal methods, such as incineration or landfilling, also produce GHGs.

6. **Discharge or Reuse**: The treated wastewater is either discharged into natural water bodies (like rivers or oceans) or, in some cases, reused for non-potable purposes like irrigation or industrial processes. The transportation of treated wastewater to discharge points may involve energy use and emissions, particularly in centralized systems.

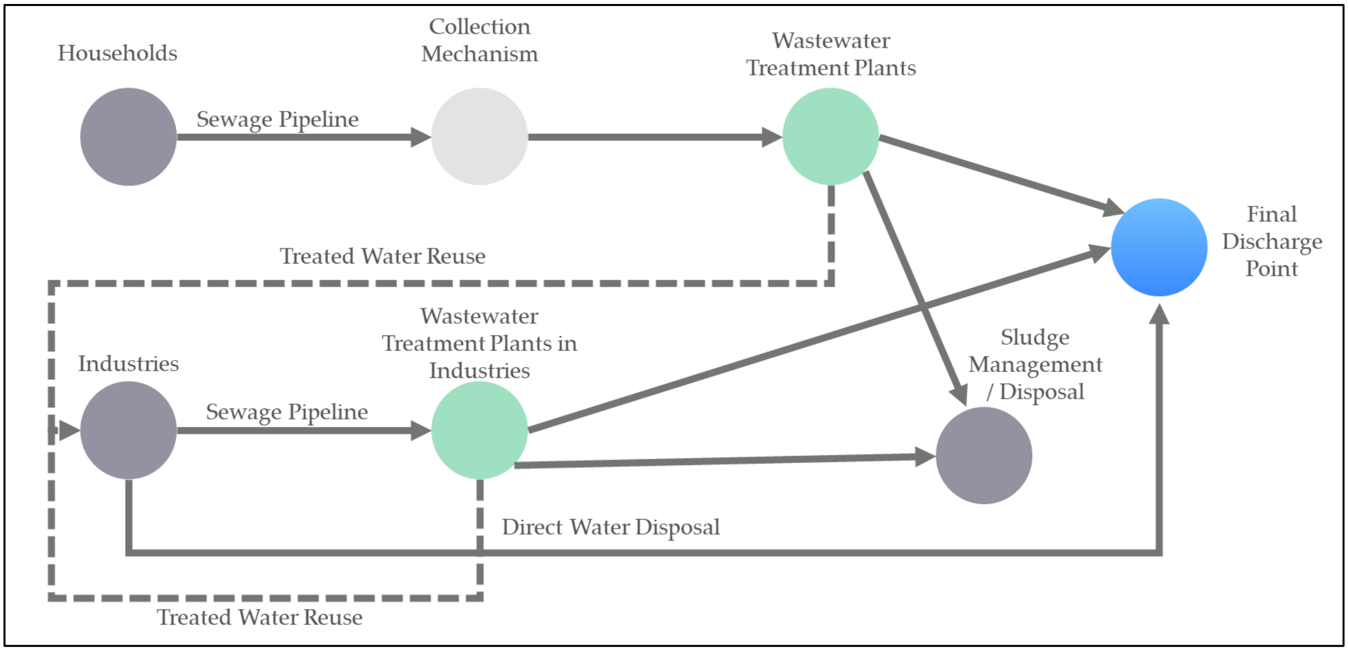

Figure 5: Wastewater Management System

Stakeholders

Stakeholders in the wastewater treatment value chain in India encompass a wide range of entities, each with its own responsibilities and contributions. These stakeholders include government agencies at various levels (central, state, and local), wastewater treatment plant operators, environmental regulators, research institutions, non-governmental organizations (NGOs), and the communities served by these facilities. Below given are the stakeholders and their roles:

1- **Ministry of Environment, Forest and Climate Change (MoEF&CC)**: Formulates policies and regulations related to environmental protection, including wastewater treatment and GHG emissions.

2- **Central Pollution Control Board (CPCB)**: Monitors and regulates pollution control standards, compliance, and reporting for WWTPs at the national level.

3- **State Pollution Control Board (SPCB)**: Enforces environmental regulations and standards within respective states.

4- **Urban Local Bodies (ULBs) and Municipal Corporations:** Implement wastewater treatment projects, manage local WWTPs, and ensure compliance with environmental standards.

5- **National Green Tribunal (NGT):** Addresses environmental disputes and violations, ensuring adherence to environmental laws in wastewater treatment.

6- **Private Sector:** Public or private entities responsible for the construction or day-to-day operations or both of treatment facilities. They collect data on wastewater inflow, treatment processes, and energy consumption. Plant operators implement strategies to reduce GHG emissions, such as optimizing treatment processes, energy-efficient operations, and the proper management of sludge.

7- **Non-Governmental Organizations (NGOs):** May be involved in wastewater treatment projects, especially in areas where access to clean water and sanitation is a concern.

8- **Research Institutions and Academia:**

  a. Conduct research on wastewater treatment technologies and GHG emissions mitigation strategies.

  b. Provide expertise and data for improving GHG estimation methodologies in the wastewater sector.

9- **Power Sector:** WWTPs are energy intensive facilities. The power sector provides the necessary electricity to run pumps, blowers, mixers, and other equipment essential for wastewater treatment.

10- **Chemical Manufacturers:** WWTPs requires variety of chemicals like coagulants, flocculants, disinfectants, pH-adjusting agents, and various specialty chemicals for effective wastewater treatment, which makes chemical manufacturers an important stakeholder in the wastewater treatment value chain.

11- **End Users of by-Products:**

  a. Industries, commercial establishments, and agricultural users who rely on treated water from wastewater treatment plants to fulfil their water needs. By using treated water, they decrease their reliance on freshwater sources, thereby conserving valuable natural resources.

  b. Farmers stand to gain significant benefits from the by-products of wastewater treatment, including biosolids and treated sewage water. These resources contain valuable nutrients such as nitrogen and phosphorus, essential for robust crop growth. By incorporating biosolids and treated sewage water into their agricultural practices, farmers enhance soil fertility and reduce their dependence on external chemical fertilizers, promoting eco-friendly and sustainable agriculture.

EMISSION ESTIMATE FROM DOMESTIC WASTEWATER TREATMENT AND DISCHARGE

Waste management activities such as collection, treatment and discharge of wastewater lead to GHG emission in the form of CH_4 and N_2O gases. GHG Platform – India (GHGPI) is a collective society initiative which provides independent estimation and analysis of India's greenhouse gases emission across various sectors. The platform published a report on National Greenhouse Gas Estimates from Waste Sector for the period 2005 to 2018 which has been taken as the major source of the data given in this chapter and the estimates given by GHG platform are then compared to the estimates given in India's 3rd Biennial Update Report submitted to UNFCC with estimate for the year 2016.

The emission estimation from domestic wastewater covers two GHGs currently: Methane (CH_4), and Nitrous Oxide (N_2O). According to the IPCC agreement, CO_2 emissions from wastewater treatment are of biogenic nature and are not included in the total emissions[12].

The 100-year Global Warming Potential (GWP) values for CO_2, CH_4 and N_2O gases are given in Table 4 below. These GWP values were initially provided by the Intergovernmental Panel on Climate Change (IPCC) in its Second Assessment Report in 1996. The GWP values from the IPCC's Second Assessment Report (AR2) have been considered to evaluate CO_2e in this report.

Table 4: Global Warming Potential as per IPCC assessment reports

Sr. No.	GHG	Global Warming Potential	
		Second Assessment Report, 1996	Sixth Assessment Report, 2022
1	CO_2	1	1
2	CH_4	21	27.9
3	N_2O	310	273

Period of Assessment:

The GHG emission estimations for the domestic wastewater sector at the state level and the resulting national-level aggregated estimates cover the time span from 2005 to 2018. The base year of 2005 has been considered as India has targeted to reduce GHG emissions by 33-55% by the year of 2030 as compared to that of the base year of 2005.

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[12] Vanessa Parravicini, Karl Svardal, Jorg Krampe, Greenhouse Gas Emissions from Wastewater Treatment Plants, 2016, 97(2016) 246-253

Approach and Emission Factor Used:

In absence of any country specific guidelines, GHGPI used IPCC guidelines which describe a single method for calculating emissions from domestic wastewater handling. GHGPI used the following equations to as per IPCC guidelines to calculate the emissions from domestic wastewater handling. As per IPCC, in developing countries, a small share of domestic wastewater is collected in sewer systems, with the remaining ending up in pits or latrines.

For CH_4 emissions:

Emissions = (Total Organic Waste * Emission Factor) – Methane Recovery

For N_2O emissions:

Emissions = Annual Volume of wastewater treated * N_2O emitted per person per m^3

or

Emissions = Total population * N_2O emitted per person per year

Table 5: Tier Approach and type of emission factor used

IPCC ID	GHG Source	CO_2		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor	Method Applied	Emission Factor
4D1	Domestic Wastewater treatment and discharge	Not Applicable	Not Applicable	Tier 1	Default IPCC	Tier 1	Default IPCC

Detailed Tier 1, Tier 2 and Tier 3 approaches to calculate GHG emissions from wastewater handling are explained in IPCC good practice guidelines and uncertainty management in National Greenhouse Gas Inventories.

Total GHG Emissions from Waste Sector[13]:

Table 6 presents greenhouse gas (GHG) emission data from the Waste Sector based on the Global Warming Potential (GWP) values from the IPCC Second Assessment Report (AR2) for the years 2005 and 2018. The data is categorized into different source categories within the Waste Sector i.e. Solid Waste & Wastewater.

Table 6: Total GHG Emissions from Waste Sector in India[13]

IPCC ID	Source Category	GHG Emission (Million Tonnes of CO_2e based on GWP values from IPCC second Assessment Report (AR2)		
		2005	2018	Percent Change (2005 – 2018)
4	Total from Waste Sector	88.23	114.50	29.77%
4A	Solid Waste Disposal	7.05	13.23	87.66%
4D	Total Wastewater Treatment and Discharge	81.18	101.27	24.75%
4D1	Domestic Wastewater Treatment and Discharge	43.82	63.76	45.50%
4D2	Industrial Wastewater Treatment and Discharge	37.36	37.51	0.40%

- The cumulative greenhouse gas (GHG) emissions from India's Waste sector in 2018 are projected to amount to 114.50 million tonnes CO_2 equivalent (CO_2e). This signifies a significant rise of 29.77% (equivalent to 26.27 million tonnes of CO_2e) compared to the figures recorded in the year 2005.
- Domestic wastewater treatment and discharge (4D1) has contributed the most to GHG emissions in the sector over the reporting period, accounting for around 55.6% in 2018. Rising volumes of domestic wastewater in urban and rural areas across states, combined with the prevalence of systems/pathways with high GHG emission generation potential, such as septic tanks, inadequately managed aerobic treatment plants, and untreated discharge of domestic wastewater, result in higher emissions for this source category.
- GHG emission from the domestic wastewater discharge have grown at CAGR of 2.9%.

GHG Estimation from Domestic Wastewater Sector (Rural & Urban):

Tabel 7 provides detailed greenhouse gas (GHG) emission estimates for rural and urban areas in India from the years 2005 to 2018, categorized into methane (CH_4), nitrous oxide (N_2O), and total CO_2 equivalent (tCO_2e) emissions.

[13] National level greenhouse gas estimates, GHG Platform India, September 2022

Table 7: GHG estimates from Domestic wastewater sector[14]

Category	GHG Estimates (Million Tonnes of CO_2e)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Rural Area	CH_4	17.49	17.76	18.04	18.31	18.59	18.86	23.06	23.46	23.87	24.19	24.59	24.99	25.40	25.80
	N_2O	11.09	11.22	11.35	11.49	11.60	11.73	12.17	12.33	12.49	12.64	12.81	12.96	13.12	13.28
	tCO_2e	28.57	28.98	29.39	29.80	30.19	30.60	35.23	35.79	36.36	36.84	37.40	37.96	38.52	39.08
Urban Area	CH_4	10.68	10.85	11.01	11.00	11.16	11.32	16.11	16.48	16.76	17.19	17.47	17.46	17.73	18.01
	N_2O	4.57	4.7	4.83	4.96	5.01	5.14	5.45	5.63	5.81	5.99	6.17	6.34	6.51	6.67
	tCO_2e	15.25	15.55	15.85	15.96	16.17	16.46	21.55	22.11	22.56	23.18	23.64	23.80	24.24	24.68
National Estimate (Rural + Urban)	CH_4	28.17	28.61	29.05	29.31	29.75	30.18	39.17	39.94	40.63	41.38	42.06	42.45	43.13	43.81
	N_2O	15.66	15.92	16.18	16.45	16.61	16.87	17.62	17.96	18.3	18.63	18.98	19.3	19.63	19.95
	tCO_2e	43.83	44.53	45.23	45.76	46.36	47.05	56.79	57.9	58.93	60.01	61.04	61.75	62.76	63.76

[14] GHG Platform India, https://www.ghgplatform-india.org/waste-sector/ Accessed on: 22nd September 2023

- Emissions from domestic wastewater treatment and discharge experienced a substantial increase of 49.01%, equivalent to 19.94 million tonnes of CO_2e, between 2005 and 2018. In 2005, these emissions amounted to 43.82 million tonnes of CO_2e, rising to 63.76 million tonnes of CO_2e in 2018. This significant growth underscores the importance of addressing emissions from this source category to mitigate their impact on overall greenhouse gas emissions.

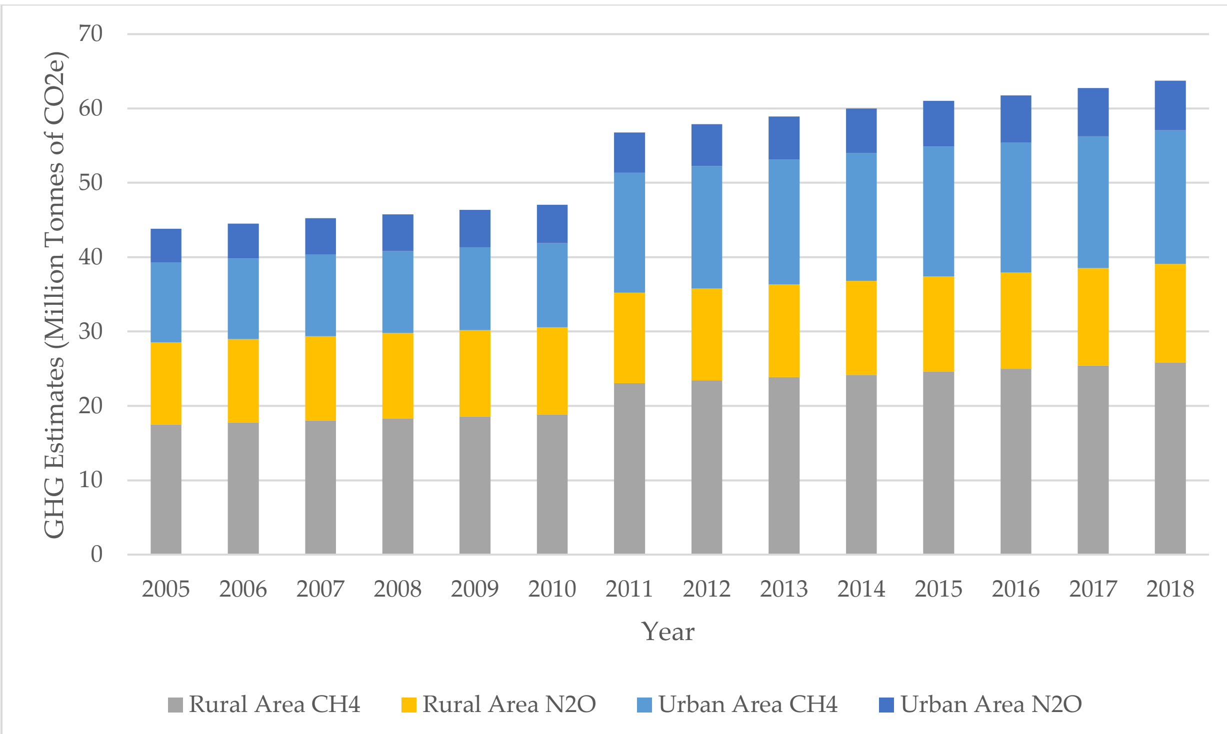

Figure 6: GHG emissions trend - Rural & Urban

- Examining the period between 2005 and 2018, CH_4 emissions from urban domestic wastewater exhibited substantial growth, increasing from 10.68 million tonnes of CO_2e to 18.01 million tonnes of CO_2e. This corresponds to a Compound Annual Growth Rate (CAGR) of 4.10%. In comparison, N_2O emissions also experienced an increase during this timeframe, rising from 4.57 million tonnes of CO_2e in 2005 to 6.67 million tonnes of CO_2e in 2018, with a CAGR of 2.95%.

- In rural areas, CH_4 emissions CH_4 emissions increased from 17.49 million tonnes of CO_2e in 2005 to 25.80 million tonnes of CO_2e in 2018. This corresponds to a Compound Annual Growth Rate (CAGR) of 3.04%. In comparison, N_2O emissions from rural domestic wastewater show a steady increasing growing with a CAGR of 1.4% to 13.28 million tonnes of CO_2e from 11.09 Million tonnes of CO_2e over the reporting period.

- Rural and urban emissions combined, the total CH_4 emissions increased from 28.17 million tonnes in 2005 to 43.81 million tonnes in 2018. N_2O emissions also rose from 15.66 million tonnes in 2005 to 19.95 million tonnes in 2018. The total tCO_2e emissions for the nation increased from 43.83 million tonnes in 2005 to 63.76 million tonnes in 2018.

- Rural areas consistently contributed more to GHG emissions compared to urban areas, with higher emissions in all categories (CH4, N2O, and tCO2e). This suggests that rural areas should be a focus for emissions reduction strategies.

- While there is a general increasing trend, it's noteworthy that emissions vary from year to year. Understanding the factors driving these variations could be crucial for designing targeted emission reduction measures.

Top 10 States in terms of Total GHG Emissions from Domestic Wastewater Sector (2005-2018)

Table 8 presents the annual greenhouse gas (GHG) emissions in million tonnes of CO_2 equivalent (CO_2e) for the top 10 states and union territories in India from the year 2005 to 2018.

- Uttar Pradesh consistently has the highest GHG emissions among the listed states, reaching 10.37 million tonnes of CO_2e in 2018. It accounted for approximately 16% of India's cumulative emissions from 2005 to 2018, making it the highest contributor.

- Maharashtra is the second-largest contributor to GHG emissions, with 6.36 million tonnes of CO_2e in 2018. It accounted for approximately 10% of India's cumulative emissions during the same period.

- West Bengal and Bihar also contribute significantly to India's emissions, with 4.53 million tonnes of CO2e and 4.33 million tonnes of CO2e in 2018, respectively. They each account for around 7% of the cumulative national emissions.

- Although Andhra Pradesh and Bihar are not in the list of top 10 wastewater generating states (refer to table 1). They are among the top 10 states having the highest GHG emissions. This might be attributed due to higher rural population or high protein intake in these states. However, a detailed study is required to reach accurate reasons.

- The data highlights the importance of focused attention in Uttar Pradesh, Maharashtra, and West Bengal, being the highest emitters.

Table 8: Top 10 states in terms of GHG emissions from Wastewater sector[15]

Total GHG emission (Rural + Urban) (Million tonnes of CO2e)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Cumulative (2005-2018)	As % of Cumulative National Emissions (2005 - 2018)
Uttar Pradesh	6.83	6.96	7.09	7.23	7.12	7.25	9.12	9.30	9.49	9.67	9.86	10.00	10.19	10.37	120.47	16%
Maharashtra	4.73	4.80	4.87	4.92	5.07	5.14	5.69	5.78	5.88	5.97	6.06	6.17	6.26	6.36	77.69	10%
West Bengal	3.48	3.52	3.57	3.61	3.62	3.66	4.13	4.18	4.24	4.29	4.35	4.41	4.47	4.53	56.08	7%
Bihar	2.79	2.86	2.92	2.98	2.99	3.05	3.57	3.77	3.86	3.95	4.05	4.14	4.24	4.33	49.50	7%
Tamil Nadu	2.85	2.89	2.93	2.96	3.07	3.12	3.51	3.56	3.62	3.67	3.73	3.80	3.84	3.88	47.43	6%
Rajasthan	2.49	2.54	2.58	2.63	2.67	2.72	3.22	3.29	3.36	3.43	3.49	3.57	3.64	3.71	43.34	6%
Madhya Pradesh	2.32	2.37	2.41	2.43	2.49	2.53	3.03	3.09	3.15	3.22	3.28	3.35	3.41	3.47	40.56	5%
Gujarat	2.19	2.23	2.27	2.28	2.32	2.36	3.12	3.18	3.24	3.30	3.36	3.30	3.36	3.42	39.93	5%
Karnataka	1.99	2.02	2.05	2.07	2.13	2.16	2.57	2.61	2.65	2.69	2.73	2.79	2.83	2.88	34.19	5%
Andhra Pradesh	3.24	3.27	3.31	3.32	3.44	3.47	4.35	4.40	4.45	2.62	2.64	2.72	2.74	2.76	46.74	6%
National	**43.83**	**44.53**	**45.23**	**45.76**	**46.36**	**47.05**	**56.79**	**57.9**	**58.93**	**60.01**	**61.04**	**61.75**	**62.76**	**63.76**	**755.70**	

[15] GHG Platform India, https://www.ghgplatform-india.org/waste-sector/ Accessed on: 22nd September 2023

National GHG Extrapolation from Domestic Wastewater Sector up to 2025

Based on the available historical data on GHG emissions in Indian states from 2005 to 2018, we used Microsoft Excel's Forecast method to extrapolate the available data of national GHG estimates up to the year 2025. This forecast model of excel predicts future values using your existing time-based data and the AAA version of the Exponential Smoothing (ETS) algorithm.

Table 9 illustrates the greenhouse gas (GHG) emissions in million tonnes of CO_2 equivalent (tCO_2e) for the years 2005 to 2018 and extrapolated to 2015 with corresponding lower and upper confidence bounds for selected years.

Table 9: National GHG Emissions extrapolation up to 2025 (Million Tonnes tCO_2e)

Year	GHG Emission (Million Tonnes tCO_2e)	Lower Confidence Bound (GHG Emission) (Million Tonnes tCO_2e)	Upper Confidence Bound (GHG Emission) (Million Tonnes tCO_2e)
2005	43.82		
2006	44.53		
2007	45.24		
2008	45.76		
2009	46.36		
2010	47.06		
2011			
2012	57.90		
2013	58.92		
2014	60.02		
2015	61.04		
2016	61.75		
2017	62.76		
2018	63.76	63.76	63.76
2019*	67.62	62.71	72.54
2020*	69.42	64.46	74.37
2021*	71.21	66.21	76.20
2022*	73.00	67.97	78.03
2023*	74.79	69.72	79.87
2024*	76.59	71.47	81.70
2025*	78.38	73.22	83.53

*Extrapolated Values

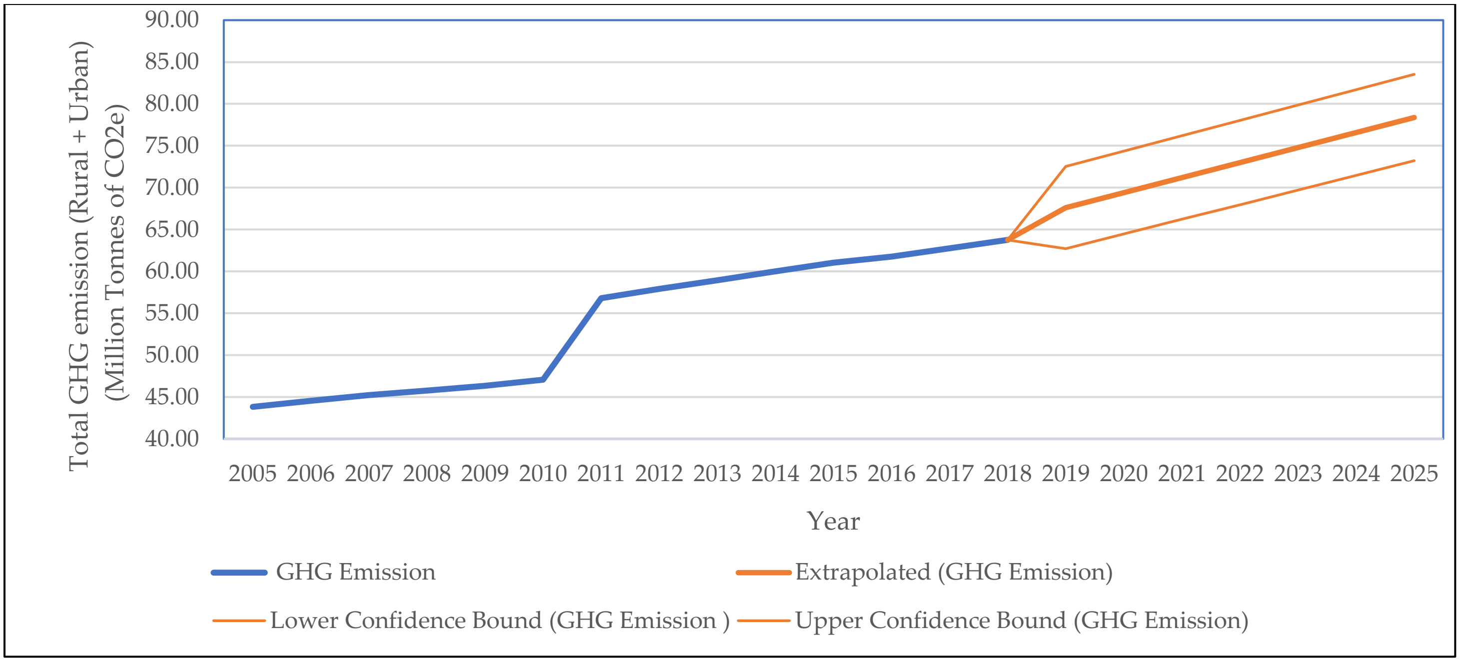

Figure 7: National GHG Emissions extrapolation up to 2025 (Million Tonnes tCO_2e)

Note: The upper and lower confidence bounds represent a range of possible greenhouse gas emissions. It's like predicting a range of temperatures for tomorrow, say between 70°F and 80°F. With 95% confidence, it means there's a very high chance (95 out of 100 times) that the actual temperature will fall within this range.

- The forecast GHG emissions for the years 2019 to 2025 continues to project an increase in emissions. The forecasted values range from 67.62 to 78.38 million tonnes tCO_2e by 2025, showing a continued upward trajectory. The upper and lower confidence bounds provide a range of potential emissions with confidence intervals of 95%.
- The substantial increase in GHG emissions from 2010 to 2011, where emissions jumped from 47.06 to 56.79 million tonnes tCO_2e, suggests a significant spike in emissions during that year.

Comparison with National Inventories

The aggregate emission estimates for the domestic wastewater sector have been compared with the following National Level GHG Estimates reported by the Government of India:

1- Indian Network for Climate Change Assessment, India: Green House Gas Emissions 2007 (INCCA)
2- India's First Biennial Update Report (BUR1) to the United Nations Framework Convention on Climate Change (having reference point of 2010)

3- India's Second Biennial Update Report (BUR2) to the United Nations Framework Convention on Climate Change (having reference point of 2014)
4- India's Third Biennial Update Report (BUR3) to the United Nations Framework Convention on Climate Change (having reference point of 2016)

Table 10 compares greenhouse gas (GHG) emission estimates reported by government of India to the estimated done by GHGPI and highlights the differences between them in percentage.

Table 10: Comparison of GHGPI estimates with reported National GHG Inventories

Category	GHG emissions estimates (Million tonnes of CO_2e)											
	2007			2010			2014			2016		
	INCCA	GHGPI	Difference	BUR1	GHGPI	Difference	BUR2	GHGPI	Difference	BUR3	GHGPI	Difference
Domestic Wastewater	22.98	45.23	**96.8%**	29.38	47.05	**60.1%**	36.68	60.01	**63.6%**	38.84	63.76	**64.2%**
Total Waste (Solid + IWW + DWW)	57.77	95.32	**65.0%**	65.04	106.61	**63.9%**	78.24	134.69	**72.1%**	75.23	114.49	**52.2%**

The GHGPI estimates for domestic wastewater show a noteworthy divergence from the corresponding official inventory estimates in BUR 3, particularly evident in the 2016 data, where there is a substantial deviation of 64.2%. Several factors may contribute to this variance, and one potential explanation is the differing consideration of treated and untreated wastewater in the estimation process. Additionally, the inclusion of emissions from rural domestic wastewater in the GHGPI estimates could further contribute to this deviation. However, it's important to note that the BUR 3 report lacks explicit clarification regarding whether CH_4 emissions from rural domestic wastewater are covered within the official estimates for 2016. Given the limited information available in BUR documents, a thorough understanding of the primary causes for the deviation between GHGPI estimates and official inventory estimates for domestic wastewater remains challenging to ascertain.

CONCLUSIONS

- India has seen a significant rise of population from 683.33 million in 1981 to 1.31 billion in 2021.

- India generates a massive 72,368 million liters per day (MLD) of sewage, highlighting the immense challenge of managing wastewater in a densely populated nation. While there is an installed capacity of 31,841 MLD distributed across 1,469 sewage treatment plants (STPs), the operational capacity stands at 26,869 MLD across 1093 STPs. However, the actual utilization of this capacity is notably lower, at 20,235 MLD.

- The cumulative greenhouse gas (GHG) emissions from India's Waste sector in 2018 are estimated to amount to 114.50 million tonnes CO_2 equivalent (CO_2e).

- The emissions from domestic wastewater sector amounted to 43.82 million tonnes of CO_2e in 2005, rising to 63.76 Million tonnes of CO_2e in 2018.

- Domestic wastewater treatment and discharge has contributed the most to GHG emissions in the waste sector over the reporting period of 2005 to 2018, accounting for 55.7% of total GHG emissions from waste sector in 2018.

- The top 10 states in terms of sewage generation (in descending order) are Maharashtra, Uttar Pradesh, Tamil Nadu, West Bengal, Gujarat, Karnataka, Kerala, Madhya Pradesh, NCT Delhi, and Rajasthan.

- The top 10 states generating highest amount of GHG emissions from domestic wastewater treatment (in descending order) are Uttar Pradesh, Maharashtra, West Bengal, Bihar, Tamil Nadu, Rajasthan, Madhya Pradesh, Gujarat, Karnataka, and Andhra Pradesh.

- From the trend above, we see that the state like Uttar Pradesh which has high sewage generation (8263 MLD), yet very low sewage treatment capacity (41%) and hence, high GHG emissions (cumulative value of 120.47 million tonnes of CO_2e).

- The forecast GHG emissions for the years 2019 to 2025 continues to project an increase in emissions. The forecasted values range from 67.62 to 78.38 million tonnes CO_2e by 2025, showing a continued upward trajectory.

- The estimates done by GHGPI show substantial variation from what Government of India has submitted in it's biennial report to IPCC i.e. of 64.2% for 2016 data, 63.6% for 2014 data, 60.10% for 2010 data and 96.8% for 2007 data.
- While GHGPI has explained the methodology, emission factor and data considered for the estimate matches the guidelines provided by IPCC. However, the biennial reports submitted to IPCC by Ministry of Environment, Forest and Climate Change, Govt. of India do not give explicit clarifications on the methodology and data used for estimation of the GHGs from domestic wastewater sector. This restricts the study to conclude any specific reasons for such huge variations in the reported estimates. Therefore, a very detailed consultation with the stakeholders and in-depth study of the methodology used by the government of India to report GHG emissions from wastewater sector is required to address the variations in reporting of the data.

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